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MATHEMATICS, MODELING, AND MODULAR CURRICULUM IN ENGINEERING RETRAINING PROGRAMS

A DISSERTATION

submitted by

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In partial fulfilment of the requirements
for the degree of
Doctor of Philosophy

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To the memory of my mother, Sharafat, and my father, Ismail
who always encouraged me to strive for educational excellence.

This doctoral study is dedicated to my wife, Farkhondeh and my daughters; Mehrnoush, Raha, and Ava, my best supporters

Acknowledgments

The outcome of this study is the culmination of efforts by numerous individuals and as Einstein once said: "many times a day I realize how much my own outer and inner life is built upon the labors of my fellow men, both living and dead, and how earnestly I must exert myself in order to give in return as much as I have received." Therefore, I will never be able to express my deepest gratitude to all of my advisers, mentors, and friends who have showed me to the true path of study, research, and accomplishment.

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Abstract

Mathematics, Modeling, and Modular Curriculum

in Engineering Retraining Programs

Engineering career is highly dependent on economic, social, and politics changes. The last wave of massive lay-offs of technical workforces and engineers in early 1990's was direct consequence of the end of the cold war and the intense global competition. To survive in a rapidly changing global market, American industries are looking for creative, innovative, knowledgeable, and skillful engineers. On the other hand, moving from industrial age into the age of information causes the technology to advance at such a rapid rate that renders engineers' knowledge and skills obsolete every few years. Consequently, engineers need to be continuously retrained and a true lifelong learning becomes a necessity and rule for engineers, as oppose to luxury and exception.

Retraining programs, indeed, are educational processes with their own unique structures. Participants in retraining programs for engineers are substantially different from traditional students. Thus, require their own special educational procedure. The present study is an attempt to probe, explore, and provide an appropriate educational method for engineering retraining programs. The central concerns and implications of this study revolve around: who engineers are, how they learn, why they need to learn, and what they have to learn. The existing retraining programs also will be evaluated in order to develop a suitable retraining program for engineers.

The study concludes that an efficient, effective, and meaningful retraining program is the one that combines and utilizes: mathematics, modeling, and modular curriculum; i.e., the most relevant elements in all types of engineering education.

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BACKGROUND

The direction of engineering careers may change from time to time because of changes in the economy and in society, and education is needed to prepare for each new direction. In recent years, cuts in the defense budget, along with automation, intense global competition, corporate downsizing, and de-industrialization have caused massive lay offs, among engineers and other technical professions. Accordingly, the rate of unemployed engineers reached its all time high of 4.08% (Bell, 1994). In other words, more than 75,000 out of 1.9 million total engineers in the United States received pink slips in the late 1980's and early 1990's. Many engineers, mostly the older ones, refocused their careers after disappointing feedback from industry. Consequently, the actual percentage of unemployed engineers has not improved notably since 1994. The recent wave of unemployment hit harder in some areas, such as the aerospace industry, than in others. The number of employees in aerospace declined from 1.34 million in 1989 to 0.86 million in 1994 (Bell, 1994). For unemployed engineers, refocus of knowledge and skill seems the only solution for re-employment since their current expertise in most cases is not marketable.

Unemployment is not the only problem that engineers are experiencing. The studies of engineering societies and high-tech employment agencies show the long term or permanent career for engineers is going to be replaced by temporary and project-to-project contracts. According to Mark Fackler, president of a California based temporary job hunting agency, "Temporary industry is growing and has

been for years...the average job [engineering] lasts nine to ten months" (Bell, 1994, p.23).

Every aspect of life is rapidly changing toward a digital world and digitalization seems to be the most recent episode in the technological evolution of an information era. At the present time, digital electronics is the dominant figure, from communication and transportation to consumer goods and medical equipment. In agreement with a shift to a digital world, on April 3,1997, the Federal Communication Commission (FCC) approved new rules, among which is a rule giving nearly 1600 broadcasters free licenses to provide high-definition digital television to viewers in the top 10 markets, starting within 18 months. According to the new rules, ultimately, digital TV will render obsolete the 240 million U.S. TV sets which are in use now. Under the new order of the FCC, the TV signals now received will no longer be broadcast after the year 2006. (Cahur, 1997). Along with departing from industrial age to the information age, technology advances at such a rate that not only the industrial design and production, but the knowledge and skill of engineers become obsolete every few years. Consequently, lifelong learning becomes a necessity for engineers, not a fashion.

To keep high standards for industrial products, American industries need a high quality technical workforce. They expect engineers to be knowledgeable, creative, innovative, and skillful. They look for those engineers who are able to

design and redesign a cost effective advanced high-tech product. Finally, they need engineers with effective communication skills in order to work in today's more diverse and multicultural workplace. In other words, at the end of the twentieth century, engineers need to be licensed Professional Engineers and become "independent economic units," to make their knowledge and skills marketable. Consequently, the title of "Professional Engineer," P.E., is expected to attract more engineers. At the present time, about 350,000 American engineers are licensed P.E.(NSPE, 1996). Although, most licensed Professional Engineers have engaged in continuing knowledge and skill training on a voluntarily basis, mandatory "Continuing Professional Competency," CPC, is going to be the required condition for license renewal. Both the National Society of Professional Engineers (NSPE) and the National Councils of Examiners for Engineers and Surveying (NCEES) endorse and support the policy of mandatory CPC for engineers. Concerning the need of continuing education for renewal of license, NSPE states: "CPC requirements, also known as continuing professional development or continuing education, mandate that professional licensees demonstrate to the licensing authority the satisfactory completion of specified activities as a condition for renewal of the individual's professional license" (NSPE, 1996, p.2).

In an era of drastic changes at the international level, engineers are not alone. The American Society for Training and Development "estimates by the year 2000, 75% of the workforce will need retraining. For most of the U.S. population, lifelong learning becomes a necessity" (Twigg, 1994, p.2). Institutions of higher education have already seen the tremendous needs for retraining. For example, at the present time, 57% of the nation's undergraduates are adult learners of age 25 or older. Traditionally younger people of age 18-22 had been the absolute majority of participants in undergraduate programs.

In response to needs of engineers and industry, both government and private educational and training agencies, including institutions of higher education, have developed a variety of retraining programs. Each of these training or retraining programs differs from others in objective, mission, goal, cost, and timing length. Not much study has been done on evaluation and assessment of these programs and participants have no choice but to rely on whatever providers claim. Therefore, there exists a need for such assessments so that participants can recognize the goals, focus, efficiency, and cost effectiveness of retraining programs before attending any of them.

While both federal and state governments spent millions of dollars to assist industries to modernize or shift their line of a product, they have no plan or have only limited and occasional programs to retrain the professional workforce. In 1992, federal and state governments spent respectively $350 million and $100 million dollars through their "manufacturing assistance programs" in order to modernize small and mid-sized manufacturing enterprises which employ about eight million technical workers (Hackwood, 1993, p.73). Conversion from military to civilian lines of products is the other major concern of government agencies. In the short period time from 1990-to-1992, federal and state government spent about $50 million to help the defense industry to become a more civilian-oriented economy (Adam, 1992, p.46). Only a few states such as California, Pennsylvania, and Minnesota have had training or retraining for engineers. In 1992 California State University at Long Beach started to offer an engineer "assistance program" founded by the National Institute of Standards and Technology (NIST). In this limited program, which is offered for engineers who work for local governments and industry, "the Engineering Problem Solving Initiative and the Continuing Engineering Education programs provide seminars for engineers" (Hackwood, 1993, p.73).

About all professional organizations and societies in the engineering field have established some type of retraining program either by offering short courses in a demanding area or some certificate programs. The Institute of Electrical and Electronics Engineers (IEEE) in conjunction with the International Association for Continuing Education and Training (IACET) offer a variety of short courses in the fields of electronics and computers for both members and nonmembers. The National Society of Professional Engineers (NSPE), in addition to its own technical workshops and seminars, offers both short courses and a certificate program through the National Technical University (NTU), a distance learning institution.

Most universities and technical colleges throughout the nation offer some sort of continuing education that helps engineers to upgrade and update their knowledge and skills. Some of these institutions, such as Northeastern University or Arizona State University, are active all around the nation and offer all kinds of programs from short courses to certificate and degree programs either at their own campuses, or in a distance learning fashion, or at an industry's site. In these "self-paced" types of programs, the provider offers a variety of courses and programs and it is totally up to a participant to find which one will suit his or her needs. In actuality, these are mostly money-driven programs that sell knowledge and skills, providing preset programs based on administrative decision with little or no input from learners. While participants of continuing education are all adults, the methods and approaches in teaching are not significantly different from regular day classes for younger students. Since either participants or industry and government pay tuition, the idea of a "cost effective" program has little or no popularity.

Traditionally, in order to grow, survive, and have better productivity, industries have provided "in-house" training for their employees. The retraining

programs at General Electric, General Motors, IBM, and Xerox are only a few examples of this category. These programs are run either solely by industry or in conjunction with an educational institution. Obviously, these types of low cost and faster return on investment programs have been designed for only those who are employed by the industry. The problem with these programs lies in their specific and narrow application and training. Usually, they have no long-term objectives because of their noncontinuous nature.

To meet the goals--efficient, effective, and meaningful training--of an engineering retraining program, engineers must change their knowledge, technical and communication skills, as well as their attitudes toward social and economic issues. They should learn about and follow all progress and development in their related fields. They should able to use the new tools and machines. They have to learn how to work and communicate in an emerging more diverse and global workplace and how to perform in a teamwork atmosphere. They should be more sensitive to society and environment and consider the factor of the economy in design and production.

The crucial factor in designing a retraining program is how to promote these changes. Retraining programs, indeed, are an educational process with their own unique structure. Development of such systems that promote the desired changes, requires well defined educational objectives and activities in order to engage participants in the learning process. Without the active engagement of participants in a retraining program, the outcome is nothing but another "dipole" model of an educational system in which teacher and learners occupy different ends of the dipole with a gap or a narrow connecting string between them. Most, if not all, of the present developed retraining programs are based on this ineffective dipole model. Consequently, along with engineers, providers should also have to make some changes and adjustments to their programs and reevaluate their approaches

toward their participants. Providers should comprehensively learn about their learners and know who they are, why they need to be retrained, how they learn, and what they should learn.

The other important factor in the development of an effective retraining program is its structure. Engineering, in a brief description, is a field in which engineers convert an idea into a reality. If this is the case, which it is, then modeling becomes the vital resource that engineers could have in order to accomplish their task smoothly and efficiently. For every attempt that people make in their daily life, they often draw a model. Modeling is a powerful tool in engineering which helps engineers to study either the already existing objects and processes or those newly designed products by means of simulating their behaviors. Consequently, modeling is an essential part of engineering work and is a blue print of a plan that shows how and why an expert does a task (Collins, Brown, and Newman, 1989).

In the early 1920's M.V. Kirpichev, a Russian scientist, developed the theory of heat modeling which made it possible for many phenomena to be modeled based on analogies between different physical processes (Vasilev, 1985). During the last seven decades, the theory of modeling has helped scientists and engineers to design more efficient products from aerodynamics to analog and digital computers. Yet, with all its potential and usefulness, modeling has not been recognized in most engineering schools in the United States. In Europe, especially in Germany and Russia, it is an integral part of engineering study and is a key factor in the area of design. Modeling could play a critical role in the era of global competition with its strong emphasis on economy of design and production. Consequently, modeling must be an essential part of any engineering education including retraining programs.

Chapter One
WHO ARE THE LEARNERS

> If the words of our leaders are taken at face value, engineering skills are indispensable ingredient for the future of our country.
>
> (Ellis,1994, p.18)

Understanding the characteristics of engineers is an essential and vital basis for developing an effective and meaningful retraining program. The term "engineer" brings to mind different meanings for different people. For people connected with railroads, an engineer is a person who operates an engine. In the hotel business, it means someone who works in the "Engineering Department" and repairs electrical appliances or plumbing systems. For army personnel, it means a person who builds bridges, forts, and belongs to the "Army Corps of Engineers." For the general public, it means a builder, a designer, or a manufacturer. These are but a few definitions of "engineer."

All the above meanings are correct when considering the perceptions of the people in the above categories. A more standard definition of "engineer" is necessary to establish a "typical" engineer's profile. The following dictionary and encyclopedia definitions are important to consider when creating this profile:

> A person who designs or makes engines, a person who operates, or supervises the operation of engine or technical equipment, a specialist in planning and directing operations in some technical field, a skillful or clever manager, member of that branch of the army concerned with engineering problems, as the construction and demolition of bridges, roads, etc.
>
> (Webster's New World Dictionary, 1986, p.463)

> A person who designs or develops structures, machines, apparatus, or manufacturing process, or works utilizing them singly or in combination.
>
> (Encyclopedia Britannica, 1964, p.391)

The definitions are very general. Alternatively, engineers and professional engineering societies define the role of an "engineer" as follows:

> Advances in medicine, transportation and home conveniences are only a few of the important changes made possible, in part, through the work of engineers. From the writing quill to satellite communications, and from covered wagons to space ships, engineers have made a world of difference to our welfare, environment and economy.
>
> (National Society of Professional Engineers, 1996, p.3)

> An engineer is a problem solver who uses technical means to make theory a reality. The engineer assesses society's needs, formulates a problem, and solves the issue using theoretical tools based primarily on mathematics and scientific observations.
>
> (Garcia, 1984, p.22)

> The engineer is concerned primarily with the application of discoveries to benefit mankind. It is his objective to design, plan, develop, and construct usable device that employ scientific principles.
>
> (Beakley, and Leach, 1984, p.22)

At the end of the twentieth century, engineers fall into more categories than ever before; yet as technology advances more divisions are likely occur in the future. The following represent the current categories of engineers based on web-site examination of most schools of engineering throughout the nation.

> Aerospace, Agricultural, Architectural, Biomedical, Chemical, Civil, Computer, Control, Electrical, Electronics, Environmental, Fire Protection, Forensic, Geotechnical, Health Care Facility, Industrial, Manufacturing, Material, Mechanical, Mining, Nuclear, Naval, Polymer, Petroleum, Quality Assurance, Reliability, Safety, Software, Solar Energy, Structural, System, Transportation, and Welding.

The history of engineering dates back thousands of years when ancient societies

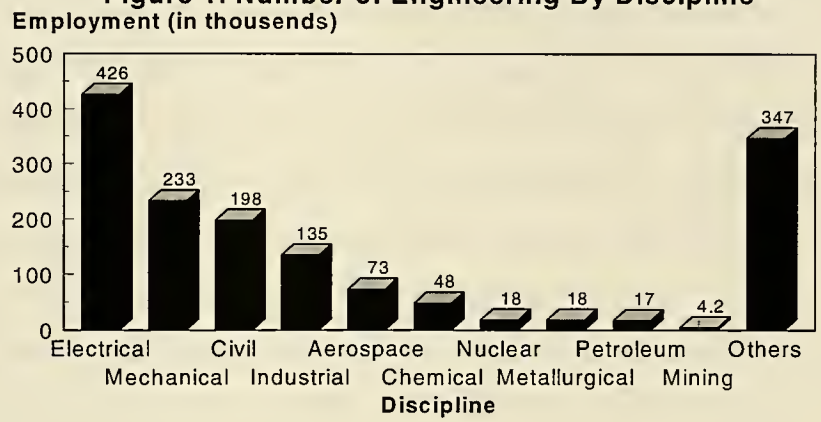
began to build the first metal tools, houses, towns, and irrigation and transportation systems. Some believe, however, that engineers--as we call them today--emerged probably in the eighteenth century. They argue that Napoleon, a great patron of the sciences, profoundly influenced engineering by establishing special schools to educate sufficient numbers of military engineers. These schools have since become the exclusive Grandes Ecoles of France which now produce the polytechnicians, the intellectual elite of the country (Gerstl and Hutton, 1966, p.2). According to this historical theory, the Napoleonic engineer was actually a military specialist. Civil, manufacturing, mining, mechanical, and chemical engineering, however, are the products of the industrial revolution. Holistic changes in society and economy in the late eighteenth and nineteenth centuries created more branches in engineering disciplines.

A combination of the space and arms races between West and East after World War II and an improvement in the consumer goods, caused technology to grow rapidly. This, in turn, diversified engineering into various specialized branches of technology. For example, electrical engineering divided into two distinct branches, electrical and electronic. Electronics further divided into two major branches: analog and digital, with many subdivisions in each. Consequently, engineers represent a much wider spectrum of professional people than ever before. "About 1.9 million Americans are engineers" (National Society of Professional Engineers, 1996, p.32). Currently, "60,000 engineering students graduate each year from programs accredited by the Accreditation Board for Engineering and Technology" (National Society of Professional Engineers, 1995, p.4). Figure 1 shows the number of engineers per discipline.

So, who are engineers? What are their characteristics: their work, thoughts, goals, personal and social behaviors? Why do they need to learn continuously? What do they have to learn? How do they learn? Obviously, engineers differ from one division of engineering to another. For example, McCaulley (1976) has used the Myers-Briggs classification system to study the personality and characteristics of engineering students. She finds that the industrial and system engineers, in two of the "people-oriented" fields in engineering, equally consist of thinking and feeling types of people, while 77% of

nuclear engineers, in a less people-oriented field, are a thinking type of people. Consequently, it is misleading to put all engineers in one category. This will result in meaningless and deceptive studies about engineers' characteristics. Nonetheless, it is necessary to examine engineers' characteristics in order to design and develop training and retraining programs. Retraining programs cannot separate the qualities of the learners from the content to be learned in order to be effective.

Figure 1. Number of Engineering By Discipline



Anatomy of Engineers.

Historically and currently, engineering connects closely with the life and economy of the community as the engineer uses his or her skills for both military and civil applications. Yet for all their contributions toward creating a modern world, engineers remain unknown to the public and they often do not receive the recognition they deserve. "Most people do not know much about engineers or what they do. For nontechnical people, engineers are too dogmatic; they think of things as either positive or negative" (Gerstl and Hutton, 1966, p.25). The public's inadequate knowledge of engineers is partly due to a lack of discourse on the part of the technical professions. This, of course, goes back to the training of engineers that focuses on what and how to do things, not on society's perception of the work of engineers. Generally, engineers prefer to do, build, or develop something rather than discuss it. This task oriented approach influences many aspects of the daily lives of engineers. Another contributing factor to

inadequate awareness of engineers is the lack of research and public discussion about engineers' personal values, creeds, and work. The following research studies provide a more meaningful and clear picture of this particular profession.

Practical, conservative, and result-oriented. A group of researchers (Gilliland, Jameton, Kash, and MacCorquodale, 1992) at the University of Arizona and the University of Nebraska conducted a two-year-long study (1990-1992) on the conversion of military technology to other market sectors. They focused on engineers because engineers are crucial resources for creative technology and consequently will play a crucial role in the economic conversion (MacCorquodale, 1993). In other words, at this transition point, the growth of the economy relies on innovation and advancement of technology, made possible in part by the work of engineers. Therefore, to convert the economy successfully, an understanding of the values and beliefs of engineers is necessary. These researchers described engineers as follows:

> Like other people, they [engineers] appreciate good pay and benefits. Of less concern is the framework of values surrounding their efforts.
> Many in the profession [engineering] have a deeply rooted optimism about the effect on society of what they do, whether or not it is defense oriented. Their time is spent on furthering technology, often at the expense of personal or social interaction in the community. Their focus is often on things, not on society's role in progress or on how to define progress.
> Engineers tend to belong to conservative organizations and to avoid political issues. They prefer to be challenged by solvable, discrete problems.
> Engineers uninterested in social change may oppose conversion simply because it represents change.
> While membership in political organizations that might influence their value systems is rare, many engineers do belong to professional societies. (p.27).

The above statement describes briefly one view of the characteristics of engineers. It indicates that engineers are conservative people who do not value social changes,

especially as they relate to their workplace. The advancement of technology concerns them more than social or personal satisfaction. They are practical and action or result-oriented people. Professional rather than political organizations interest them more.

On the political leaning of engineers, it is interesting to note that there are only two governors who also are engineers, a Republican (Mississippi) and a Democrat (Kentucky). In the 105th congress, there will be only two congressmen who are engineers, both Republicans, from Texas and Indiana. The National Society for Professional Engineers (NSPE, 1995) was an active supporter of both the Mississippi governor and the Indiana representative, suggesting a conservative idealogy. Actually, in terms of engineers' occupational role, they are considered middle class people and traditionally a high percentage of the middle class is politically conservative. On the issue of conservatism among engineers, in a comparison between scientists and engineers with similar social origins, religious affiliations, and parental political preferences, "60% of the scientists voted Democratic, while 80% of the engineers voted Republican." Not only party preference, but other indicators such as liberalism, show that "the political values of engineers are closer to those of management than are the values of scientists" (Gerstl and Hutton, 1966, p.145). Remarkably, at the Massachusetts Institute of Technology (MIT online) there are five registered political and social groups: republicans, libertarians, pro-life, radicals for capitalism, and student association for freedom of expression. Twenty-two religious groups, including seventeen Christian groups, are also active on campus. Clearly, these future engineers are conservative, even during the formal engineering study.

Interestingly, there are more associations and societies for engineers than for any other professional groups in the U.S. Besides at least one society for each branch of engineering, there exist some societies that focus on specific race or ethnic groups such as the National Society of Black Engineers (NSBE), or on narrow specialities such as the American Association of Rubber Engineers (AARE). There are also some umbrella organizations such as the National Academy of Engineering (NAE), or the National Society of Professional Engineers (NSPE). Some of these societies like the Institute of

Electrical and Electronic Engineers (IEEE) have become more international and more powerful. Yet, in tune with their members they focus on technology rather than anything else. Obviously, engineers prefer affiliations with other engineers.

Thus, engineers tend to be more result than process-oriented types of people, and are more concerned about their technical work and advancement of technology than personal or society's satisfaction. They often oppose any restriction and regulation, especially from non-technical offices such as government agencies. This may also explain why they are more interested in joining a technical or professional rather than political society or organization.

Mentoring and professionalism. In 1995, the National Society of Professional Engineers investigated interests and opinions of younger engineers (under age 35). NSPE conducted a survey by sending an inquiry of thirty- six questions to 5,200 members and nonmembers. The 1344 survey responses (NSPE, 1995) yielded the following findings:

1. Younger members want to associate with NSPE, but do not feel the need to participate actively in either local, state, or national political organizations.
2. There is a high interest in respondents for networking with other professional engineers, seeking professional development opportunities, and participating in the Continuing Professional Competency programs.
3. Mentors are wanted by large numbers of young engineers. About 80% of young engineers get information from senior, experienced colleagues.
4. A majority of respondents belong to professional societies.
5. Influencing government, at any level, is not a high priority of young engineers. (p.6).

According to this study, the philosophy of mentoring and mentorship is very popular with the majority of engineers. Even early in the history of engineering education, mentoring was important, since apprenticeship was the only method of training. Under the apprenticeship method of teaching, an experienced and knowledgeable person in the field explained and demonstrated to his students how a certain type of machine or system

worked.

Myers-Briggs Type Indicator. Personality and characteristics of engineers, how they interact with the inner world of ideas or the outer world of action, how they collect necessary information, and how they draw conclusions and make decisions are reinforced during their college education by the very methods of that training. Therefore, familiarization with engineering students' behavior, attitudes, and approaches to a given problem will help to retrain them more effectively. The Myers-Briggs Type Indicator, MBTI (Myers, 1962) is one of the instruments most used by educators, military, and industry to learn about the characteristics and personality of a specific group of people. The MBTI developed from "Psychological Types" according to Swiss psychologist, Carl G. Jung's (1971) theory.

In the late 1970's and early 1980's the University of Florida and a consortium of eight universities[1] conducted two different studies to investigate the effect of psychological type differences of engineering students. The entry test of 3,362 students at the University of Florida (McCaully, 1976) was the basis of the first study. The data in the second study were collected from 3,718 students from eight engineering schools (McCaully et al., 1983). These studies investigated how students' interests flowed, how they preferred to perceive, how they preferred to make decisions or judgments, and finally how they preferred to live, according to the Myers-Briggs Type Indicator. It is worthwhile to glance at the results of both research studies to gain a comprehensive picture of engineers.

1. People have fundamentally different attitudes toward the world. They are either "extraverted" (E) or "introverted" (I). Extraverted attitude refers to one in which attention flows out toward the objects and people of the environment. Introverted attitude refers to one in which energy flows from the object to the subject. An extravert is an action-oriented, sociable, outspoken, and impulsive person, while an introvert prefers

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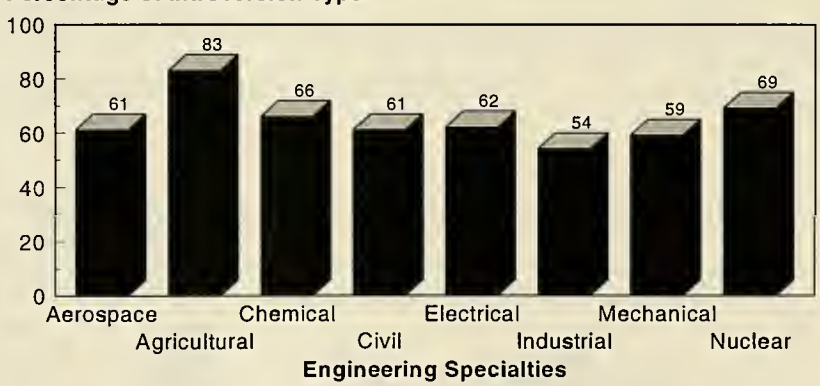
[1] The universities which participate in this study were: U. of Alabama, Clemson U., Cleveland State U., Colorado School of Mines, Cooper Union, U. of Florida, U. of Houston, and Indiana U./Purdue U. at Indianapolis.

contemplation and deliberation. An introvert prefers a clear conceptualization of events.

The results of the first study show that 62% of engineering students are introverted types varying from 54% for industrial & systems and 83% for an agricultural engineer (Figure 2). This study also shows that pharmacy is the only field of study which has a higher percentage rate of introversion (69%) than engineering. One of the noticeable results in this study is that those less people-oriented disciplines in engineering, such as agricultural and nuclear, attract more introverted people. For these groups of engineers, the end result of their work is more important than its impact on society.

Figure 2. Ranking of Engineering Specialities by Introversion



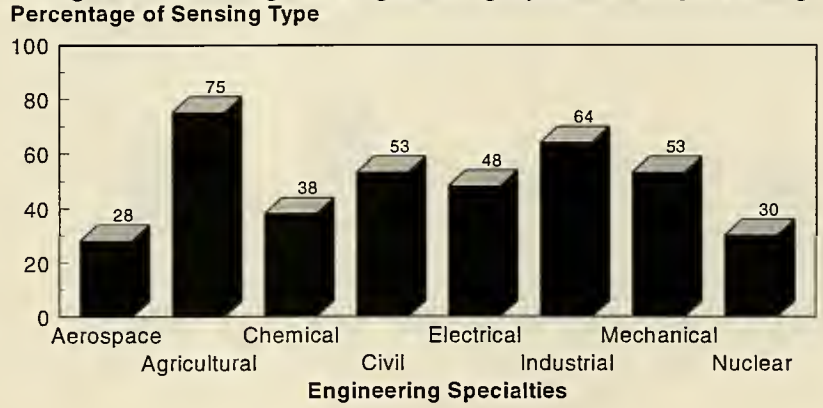
The results of the second study show that 56.3% of male and 45.2% of female engineering students are introverted types. Although the results of one study are slightly (6% on average) incongruent, both display that engineering students prefer introversion in a ratio of almost two to one. These studies show that engineers are goal-oriented people who have a strong desire to get the job done, do something, and accomplish a given task without much reflection on the process of the practice or its outcome.

2. People take two opposite ways to become aware, "sensing" (S) and "intuition" (N). Sensing types perceive through the senses of sight, sound, texture, weight, and the like. A preference for sensing leads to the development of the power of observation, and

to an interest in what is concrete, tangible, and real. Sensing types often have great knowledge of facts and details and a respect for realistic and practical matters. Sensing types tend to benefit from explicit instructions, starting with their practical experiences, or with a step-by-step approach in presenting a new material. On the contrary, intuitive types perceive things beyond the immediate reality. Intuitive types see possibilities, the meaning and relationships of events and the imaginative side of life.

The results of the first study show that 52% of engineering students are sensing types. This study also shows that applied fields attract more sensing types, while fields concerned with theory, imagination, and interpretation attract more intuitive types. For example, agricultural, civil, and industrial & system engineering, which are less theoretical and more practical fields, have the highest percentage rate of sensing types. Aerospace, nuclear, and electrical engineering, which are more theoretical fields, have the lowest percentage rate of sensing types (Figure 3).

Figure 3. Rankings of Engineering Specialties by Sensing

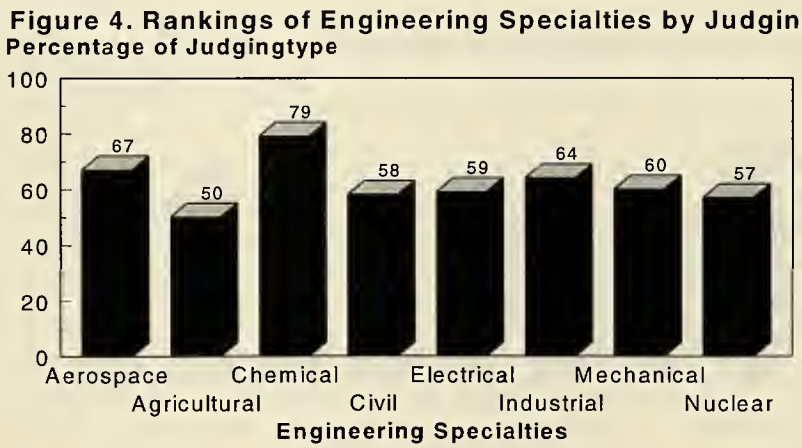


Engineering, however, is a combination of theoretical and practical fields, and attracts both sensing and intuitive types of people. The results of the second study show that 52.9% of male and 51.3% of female engineering students are sensing types. These two studies also show that engineers are more visual and analytical types of people. Both studies, however, suggest that engineering students divided almost equally between the practical sensing and the innovative intuitive types.

3. People's preferences in dealing with the environment are either "perception" (P) or "judgment"(J). Judging types prefer to gather just enough information to make a decision. They tend to become decisive people who like to have a system and a plan. Judging people tend to preserve things and oppose changes. They are a determined type of people who aim to regulate and control events. They are decisive, explicit, precise, practical, and constructivistic people who like to have a system and plan. In theory, professions requiring systems and regulations expect to attract a more judging type. On the other hand, those with a perceptive attitude tend to be open, curious, and responsive people, alert and adaptive to changes. Their aim is to understand life and to adapt to it. Professions requiring adaptability to change expect to attract perceptive types.

The results of the Florida University study show that judging types lead the fields of engineering comprising 62% of all the students. This composition varies from 50% for agricultural engineering to 79% of chemical engineering (Figure 4).

Figure 4. Rankings of Engineering Specialties by Judging

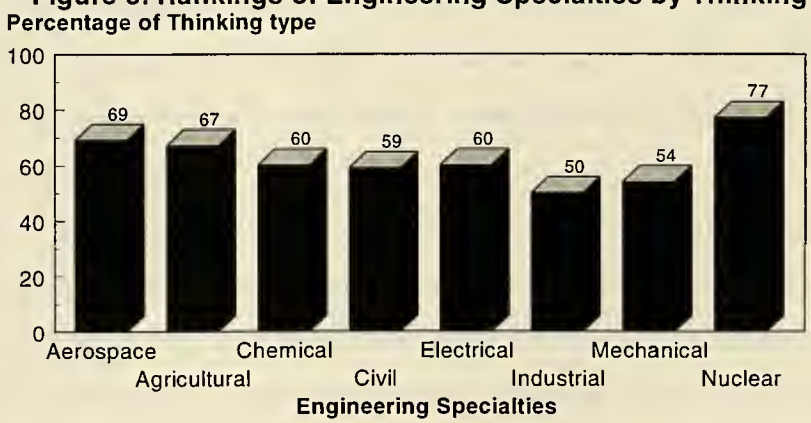


According to study of the consortium of eight universities, 60% of male and 65.3% of female engineering students are judging types. Both studies show that the ratio of judging to perception types among engineering students is two-to-one. Actually, these results might be expected from engineering professions, because to invent, design, or build a product, one needs to have a desire to control events, to have a positive attitude, and to begin to do work with available information, not to wait until one has everything in hand.

4. Thinking (T) and feeling (F) are two ways in which people come to conclusions. "Thinking" and "feeling" are two distinguishing coherent processes of decision-making. Those who reach a conclusion through objective analysis, attending to cause-and-effect in a logical way are thinking types. Thinking types are naturally attracted to professions where they can work with materials that follow the laws of cause and effect. Thinking types are more interested in the technical side of a problem rather than the human side of project. They tend to do whatever is logical and not to bother with convincing people. However, those who reach a conclusion through setting priorities according to their values, emphasizing the human side of a problem, and not sacrificing long-range values for short-term solutions are feeling types. Feeling type people are attracted to professions where knowledge of people is important.

The results of the Florida University study show that 59% of engineering students are thinking types, as Jung predicted. This ratio varies from 50% for industrial and system engineering and 77% for nuclear engineering (Figure 5).

Figure 5. Rankings of Engineering Specialties by Thinking



The study of the consortium of eight universities shows that 77% of male and 61.4% of female engineering students preferred the thinking type of decision making. Although, the percentage of thinking types in the second study is 7% (an average) more than the first study, both studies show that engineering students as a group are more thinking types than feeling, at a ratio of two to one.

According to the first study, "there are both ISTJ (Introverted-Sensing-Thinking-Judging) and ENFP (Extraverted-Intuitive-Feeling-Perceptive) personalities in engineering, and each has an important place in the engineering profession. The ISTJ types make a "decision with thinking, with trust in the answers derived from objective analysis." For ENFP types "the approach to problems is to plunge in, watching for developments, and changing the plan to take advantage of what turns up." ISTJ types also form the highest percentage in the second study with 15.2% for freshmen and 17.7% seniors. The second highest percentage goes to ESTJ type with 12% for freshmen and 8.2% for seniors. According to the latter study, however, only a small percentage of engineering students, either freshmen or seniors, are ENFP types with 4.9% and 2% respectively. Thinking and judging types who are logical and decisive people form the highest percentage for both freshmen and seniors with 45.7% and 55% respectively. While the lowest percentage goes to intuition and feeling types with 17.3% and 9.2% for freshmen and seniors respectively. The remarkable finding in these two studies is that as groups of engineering students advance from freshman to senior year, their group profile changes rapidly from predominant in feeling to thinking types. In other words, when students who become engineers are more skeptical and tend to make decisions based on logic and rules, not on personal and humanistic considerations. Table 1 displays the results of the second study.

Thus, engineering students are more introverted, sensing, judging, and thinking types of people. In other words, they are goal-oriented people who are devoted to their work. They are practical types of people and interested in what is concrete and real. They prefer sequential or step-by-step problem-solving approaches. They are analytical and interested in advancement of technical work rather than in its impact on society and people. Although all of the engineering groups are more ISTJ types than other types, there are many individual engineers with mixed types as well.

Table 1. Type table for freshman and senior engineering students at Cleveland State University.

	ISTJ	ISFJ	INFJ	INTJ
Freshmen	15.2%	5.6%	4.2%	9.5%
Seniors	17.7%	5.2%	2.3%	9.6%
	ISTP	ISFP	INFP	INTP
Freshmen	6.1%	2.8%	4.8%	7.1%
Seniors	5.6%	2.0%	3.0%	6.1%
	ESTP	ESFP	ENFP	ENTP
Freshmen	3.9%	2.2%	4.9%	4.9%
Seniors	4.8%	2.9%	2.0%	5.1%
	ESTJ	ESFJ	ENFJ	ENTJ
Freshmen	12.0%	4.5%	3.4%	9.0%
Seniors	18.2%	3.9%	1.9%	9.5%

Brain dominance. College education trains engineering students to be more left brain type thinkers. After graduation, no drastic changes will likely occur in the way they think, since their colleagues and associations are also most likely engineers. Actually, there is not much difference between college and workplace atmospheres in approaching a problem. Hudspeth, who criticize the domination of left brain learning in educational systems, explains the reasons behind this situation. He states, "...unfortunately, educational processes have been dominated by left-brain learning. It is quicker, easier, and more measurable than right-brain learning; it fits closer to learning objectives. Advanced degrees tend to select students most successful at left-brain operations, and these students subsequently become the educators" (Hudspeth, 1994, p.4). In theory, left brain thinkers are those who tend to be sequential, linear, concrete, analytical, independent, positive, explicit, goal-oriented, and verbal types of people. On the other hand, right brain thinkers are those who tend to be holistic, symbolic, intuitive, cooperative, spontaneous, emotional, process-oriented, non-verbal types of people

(Sperry, 1974). However, the following question arises: are engineers really left-brain types of thinkers? To answer this question, one may look at what and how engineer students start to learn and think about a engineering problem. For example, consider an electrical engineering student. The first subject of the undergraduate electrical engineering course is Ohm's law, which is based purely on a linear function. Ohm's law, in fact, is the fundamental of electrical engineering and students will build their electrical knowledge on this foundation. On the other hand, the curricula of most engineering schools have been developed to deliver knowledge to students and students act as "received knowledge" agents not "constructed knowledge" agents. Therefore, based on the contents of at least undergraduate engineering subjects and the curricula of engineering schools, engineering students become more linear types of people. The holistic type of engineers are mainly the products of the prestigious engineering schools such as MIT and CalTech. Where they educate students to become more "constructed knowledge" agents.

In cases where the behavior of a device or a system is not linear, students are taught to simplify it and use an approximation method to change it to a linear mode. For example, the behavior of the diode, a simple p-n junction, is not linear and for a "typical" undergraduate student who takes the related course, it is hard to analyze and solve an electronic circuit including a diode. Therefore, linearization of the diode's behavior takes place and they apply the third approximation in order to solve the given diode circuit. This method of step by step approximation by forgetting the "unimportant" detail or reduction of the independent variables, which is known as abstraction, will make engineering students more sequential, logical, analytical, concrete, and linear.

Thus, most engineering study begins with the college education; when students learn how to linearize a problem or a system by forgetting the "unimportant" variable. Linearization is a sequential progression that converts a natural behavior to an ideal and concrete mode. The next task of engineering students is to analyze and quantitatively solve the obtained linear problem or system. The outcome of this process either is desirable and students develop a working system or there is a new approach needed to

accomplish the given task. In this kind of educational environment, a successful student is the one whose problem-solving approach and effort ends with a correct answer. Engineering students, however, through this process of learning and practicing, become strongly left-brained professionals who are highly committed to their practical work. As a result, engineers as a group have a strong desire for freedom of practice, especially from government rules and regulations. Many engineers believe if the trend of "when man moved on...the law moved on to prohibit what might hurt others" (Markey,1981, p.94) were continued, then "everything in life would be ordered or forbidden and engineering practice would be hopelessly constrained by regulations designed to generate a riskless society" (Pletta, 1984, p.94). Engineers'"preference for pure leisure" which is rooted in their characteristics "is considerably stronger than that found among other occupational groups" (Gerstl & Hutton, 1966, p.152).

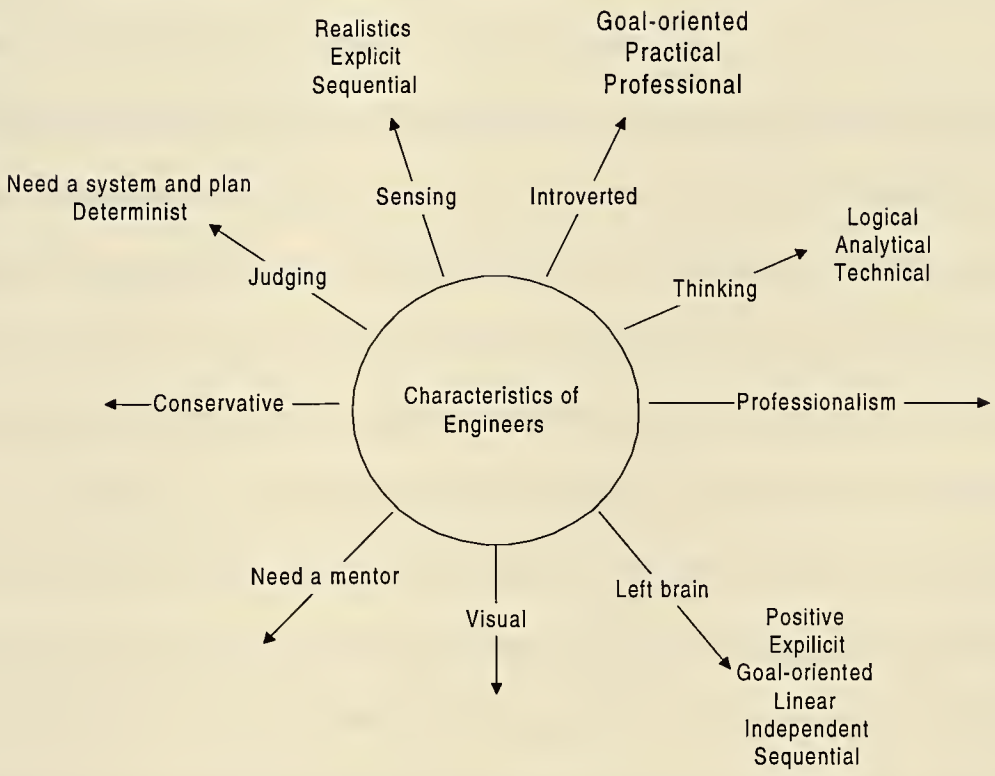
It is customary that engineers seek help only if they are puzzled with a problem and have difficulty in interpreting and solving it. In this situation, they try to reach out to a person who is an expert in that particular field.

The verbal characteristic of the left-brain category is the one that may not agree with engineers' personalities. Since engineering is a field of graphs, shapes, formulas, and diagrams and engineers need these tools to present or materialize their works, engineers are often more visual and spatial than verbal types of people. As Rosati (1996, p.7) indicates, "engineering is a highly visual subject and makes important use of diagrams, drawing, charts, computers, and laboratory work."

Summary. To develop a meaningful and effective retraining program in an active learning environment, it is necessary to understand the participants' characteristics and their needs comprehensively. According to several available studies on engineers and their personalities and characteristics, engineers are people who prefer to build or develop something rather than discuss it. They are result-oriented people who have strong desire to get the job done. Engineers are more interested in what is concrete, tangible, real, and practical. Most engineers tend to benefit from explicit instructions, starting with their

practical experiences and sequential presentation. The majority of engineers tend to be decisive, determined, and constructivistic people who prefer to have a system and a plan. They like to reach a conclusion in a logical and analytical way. In general, they are introverted-sensing-thinking-judging types of people. Engineers are more left-brain type of thinkers, which means they tend to be sequential, linear, analytical, independent, verbal, and explicit. They are conservative people who are more concerned about their technical work and advancement of technology than personal or social satisfaction. Engineers often oppose any restriction and regulation especially from non-technical people or government agencies. The philosophy of mentoring and mentorship is very popular with the majority of engineers. Figure 6 shows the overall characteristics of engineers.

Figure 6. The overall characteristics of engineers.



Chapter Two

HOW ENGINEERS LEARN

Learning is a complicated interactive process involving learners and teachers within an educational setting. The teaching and learning process is also affected by society, the school environment, and the past learning experiences of the learners and the teachers. To find out *how* engineers learn, it is important to known *who* engineers are. In Chapter One, the characteristics of engineers were reviewed but other issues remain to be discussed. The participant who attends an engineering retraining program is not only an engineer but also an adult person. Consequently, to provide a comprehensive study on how engineers learn, the characteristics and learning styles of adults in general should be taken into consideration, in addition to those of engineers.

Characteristics and objectives of adult learners. The definition of adult learners--their age, characteristics, needs, and what they want to learn--varies widely from study to study. According to Johnstone and Rivera (1965, p. 95), "The adult education participant is just as often a woman as a man, is typically under forty, has completed high school or more, enjoys an above average income, works full-time, and most often, has a white-collar occupation, is married and has children, lives in an urbanized area, and more likely, in a suburb rather than a large city, and is found in all parts of the country, but more frequently in the West than in any other region." This study shows adult education raises such indicators of socioeconomic level as occupation, income, and education. Figure 1 illustrates the relationship between occupation and participation. Obviously, many

changes have occurred in adult learners and adult education since 1965, the time this study took place, and the number of adult participants in continuing education has increased significantly during the last decades.

Figure1. Ratio of participants to nonparticipants in adult education occupation

The National Center for Education Statistics (NCES) conducted six surveys between 1969 and 1984. The outcome of their study differs substantially from that of Johnstone and Rivera's study. In the NCES survey, adult learners are defined as: "Persons beyond compulsory school age (seventeen and over) who are not enrolled full-time in a regular school or college program, but who are engaged in one or more activities of organized instruction." [Oline].

Obviously, other studies may present different views on the issue of adult learners, and perhaps all are correct for a specific group of adults with particular needs and goals. The participants of an engineering retraining program are primarily 25 to 50 year-old college graduates with a full time position, temporary employment status, or unemployed. They represent a variety of the people with different backgrounds--race, ethnicity, color,

and country of origin--and live all over the nation. Consequently, a successful engineering retraining program is one that has developed on the specific characteristics not only of adults but also of engineers.

The human life cycles. As a human grows, his or her life goes through many changes and cycles. The adult's growth and development apply to changes, either in an orderly progression or preprogrammed fashion, in the adulthood life cycle. Some believe adults move toward closely specified goals like self-actualization, "...the full use of talents, capacities, potentialities, etc." (Maslow, 1970, p.150), or toward a more fully integrated sense of ego (Loevinger, 1976), or view adult development as more dialectical, with no specific other than continued growth and change (Tennant and Loevinger 1978, Online).

Knowles sees the life cycle as the changing pattern of interest and divides the human life into three cycles of "young adults (age eighteen to thirty-five years) as they seek to establish themselves in work and home. In middle adulthood (age thirty-five to fifty-five) these concerns decrease in favor of interests in civic and social activities and in health. As individuals near the age of retirement, their area of interest comes to be occupied largely by concerns for cultural and interpretive aspects of life" (1980, p. 91). Levinson (1978) divides the male life cycle--a period that has its own particular and unifying qualities, which have to do with the character of living--into four basic stages. Pre-adulthood is a period in which men feel relatively dependent, vulnerable, and growing in the most elemental sense of the term. Early adulthood ordinarily begins at age seventeen or eighteen and ends at about age forty-five. In this period, men struggle to establish their place in society. This effort is both satisfying and stressful. As compared

with later stages, early adulthood is distinguished by its fullness of energy, capability and potential, as well as external pressure. Middle adulthood is a time in which most men go through a mid-life change in both style of work and living. Whereas early adulthood produces qualities of strength, quickness, endurance, and output, in middle adulthood other qualities can ripen: wisdom, judiciousness, magnanimity, unsentimental compassion, breadth of perspective, the tragic sense. Middle adulthood can be an era of personal fulfillment and social contribution. Late adulthood starts in the early sixties. The character of living is altered in fundamental ways as a result of numerous biological, psychological and social changes. This stage needs to be recognized as a distinctive and fulfilling season in life.

Based on Knowels' adulthood stages, participants in an engineering retraining program are in the middle and end segments of early adulthood and almost the first half of the middle adulthood. These are the people who are in a process of changes in style of living and work with lots of potential and capability and also have more perspective and maturity of wisdom. Consequently, the atmosphere and delivery system of a retraining program must be drastically different from day college classes for younger people especially when offered by universities.

Learning Theories. There are several theories that are commonly used to describe and explain how people learn. In general, however, learning theories can be divided into two major categories: those that define learning as a process by which behavior is changed, shaped, or controlled, and knowledge, skills, and attitudes are acquired (Skinner, 1968), (Boyd, 1980); and those that define learning in terms of growth, development of

competencies, and fulfillment of potential (Rogers, 1969). Learners may vary in terms of age and characteristics from one theory to another. Each learning theory has its own type of instruction that may differ totally from others. The following learning theories may be applicable for an engineering retraining program.

Bruner's constructivist theory (1990): According to constructivist theory, learning is an active process in which learners construct new ideas or concepts based upon their current and past knowledge. The principles of Burner's theory are:

1. Readiness: instruction must relate to experiences and contexts that make the student willing and able to learn.
2. Spiral organization: instruction must be structured so that it can be easily grasped by the student.
3. Going beyond the information given: instruction should be designed to facilitate an extrapolation and/or fill in the gaps. [Online]

In the constructivist theory, the learner selects and transforms information, constructs hypotheses, and makes decisions relying on a cognitive structure. Cognitive thinking provides meaning and organization to experiences and allows the individual to go beyond the information given. According to this theory, the teacher's role is to present information in a way that matches the learner's current state of understanding and to try and encourage students to discover principles by themselves.

Gagne's (1985) condition of learning theory: According to this theory, there are several different types or levels of learning that each require different types of instruction. Gagne classifies five domains of the learning process as follow:

1. Motor skills, which develop through practice.
2. Verbal information, which is required to be presented within an organized, meaningful context.
3. Intellectual skills, which appear to require prior learning of prerequisite skills;

4. Cognitive strategies, which require repeated occasions in which challenges to thinking are presented.
5. Attitudes, which are learned most effectively through the use of human models. (pp.3-4).

The principles of Gagne's theory can be summarized as follows: Different modes of instruction are required for different learning outcomes and, for learning to occur, specific conditions of learning need to be present. The specific operations that constitute instructional events are different for each different type of learning outcome. Although Gagne originally developed his theory in a military setting, it has been adopted in other settings especially in training and adult education.

Harris and Schwahn (1961) theorized that learning is essentially a matter of change due to experience. According to this theory, three categories in learning can be distinguished:

1. Learning as a product which emphasizes the end result or outcome of the learning experience.
2. Learning as a process which emphasizes what happened during the course of learning experience.
3. Learning as a function which emphasizes certain critical aspects of learning, such as motivation, retention, and transfer. (pp. 1-2).

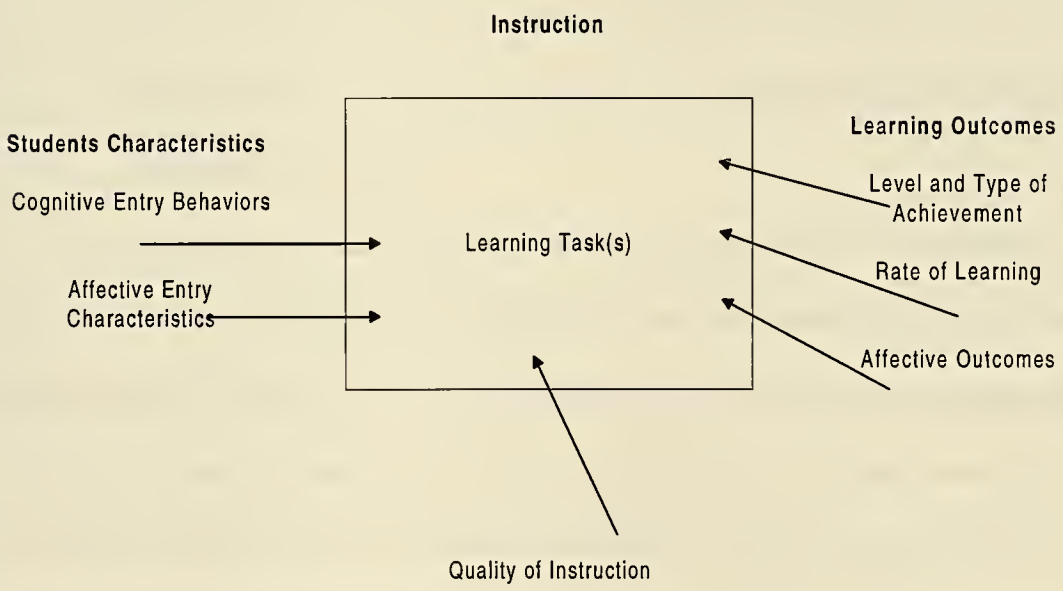
Bloom's theory of school learning (1976). His theory deals with three important elements: student characteristics, instruction, and learning outcomes. Based on this theory, the following independent variables account for the greatest degree of variance in student learning:

1. Cognitive entry behaviors, the extent to which the student has already learned the basic prerequisites to the learning to be accomplished.
2. Affective entry characteristics, the extent to which the student is or can be motivated to engage in the learning process.
3. Quality of instruction, the extent to which the instruction to be given is

appropriate to the learner. (p.7).

Bloom hypothesized that when cognitive and affective entry behaviors and qualities of instruction are appropriate, learning will be at a high level and there will be relatively little variation in student outcomes. Figure 2 shows Bloom's variables in the theory of school learning.

Figure 2. Bloom's variables in the theory of school learning



Learning theories and retraining programs. The diversity of the above-mentioned learning theories shows that learning and teaching are truly complex processes involving many issues such as learners' characteristics, past learning experience, and method of instruction. To develop an effective retraining program some basic concepts must be borne in mind.

1. Instruction must be concerned with the experiences and contexts that make the

student willing and able to learn.

2. Teachers should try and encourage students to discover principles by themselves. Different types of instruction are required for different learning outcomes.
3. The specific operations that constitute instructional events are different for different types of learning outcome.
4. Learning has three distinguishable categories: process, function, and product.
5. Cognitive entry behaviors--the extent to which the student has already learned the basic prerequisites to the learning to be accomplished--plays a crucial role in the learning process.

To develop an effective teaching and learning environment for a retraining program, it is necessary to understand that people learn differently and therefore need different instruction and attention. Consequently, the providers of retraining programs should not to restrict themselves to one particular style but should rather consider all varieties of learning styles and employ the instructional method or methods that are suitable in their particular setting.

How adults learn. The participants of retraining programs typically have already been exposed to one or more learning and teaching methods. Regardless of their motivation for attending the retraining program, they truly understand the necessity of attendance. They clearly know that continuing education is the key to success in order to keep their present job, stay competitive in the job market, or be re-employed. But the methodology that providers of retraining programs take to approach participants plays a key role in a

meaningful and effective retraining program. On this issue, Lindeman (1926) has a very interesting view. He writes,

> The approach to adult education will be via the route of situations, not subjects.... In adult education the curriculum is built around the student's needs and interests...subject matter is brought into the situation, is put to work, when needed. Texts and teachers play a new a secondary role.... The resource of highest value in adult education is the learner's experience.... Adult education is an attempt to discover a new method and create a new incentive for learning; its implications are qualitative, not quantitative. Adult learners are precisely those whose intellectual aspirations are least likely to be aroused by the rigid, uncompromising requirements of authoritative, conventionalized institutions of learning. (pp.8-9).

According to Knowles (1984) the five key assumptions of Lindeman about adult learners are:

1. Adults are motivated to learn as they experience needs and interests that learning will satisfy; therefore, these are the appropriate starting points for organizing adult learning activities.
2. Adults' orientation to learning is life-centered; therefore, the appropriate units for organizing adult learning are life situations, not subjects.
3. Experience is the richest resource for adult learning; therefore, the core methodology of adult education is the analysis of experience.
4. Adults have a deep need to be self-directing; therefore, the role of the teacher is to engage in a process of mutual inquiry with them rather than to transmit his or her knowledge to them and then evaluate their conformity to it.
5. Individual differences among people increase with age; therefore, adult education must make optimal provision for differences in style, time, place, and pace of learning. (p.31).

A training or retraining program is designed for a specific time and subject. Participants have no second chance; therefore, both provider and instructor must create the most effective learning environment possible. Knox and Sjorgen (1965) offer some interesting insights:

1. The average older adult in an adult education program is at least as intellectually able, and performs as well as, the average younger participant.
2. Adults who continue to participate in educative activity learn more effectively than similar adults who do not. This would simply seem to indicate that learning skills require practice to be maintained.
3. Adults learn far more effectively when they are permitted to learn at their own pace. (pp.133-137).

These statements are invaluable for an engineering retraining program. In fact, studies show that in the most effective retraining programs (discussed later), self-instruction materials plays an important part. Self-instruction materials, along with creation of modular retraining programs, help participants to learn at their own pace.

Although participants of retraining programs know perfectly *why* they need to acquire new knowledge and skills, they nonetheless need to be motivated too. In this regard, Lippitt and This (1983) enumerate several important conditions accepted by training directors and psychologists, as follows:

1. Acceptance that all human beings can learn.
2. The individual must be motivated to learn.
3. Learning is an active process, not passive.
4. Normally, the learner must have guidance.
5. Appropriate materials for sequential learning must be provided.
6. Time must be provided to practice the learning.
7. Learning methods, if possible, should be varied to avoid boredom.
8. The learner must secure satisfaction from the learning.
9. The learner must get reinforcement of the correct behavior.
10. Standards of performance should be set for the learner.
11. A recognition that there are different levels of learning and that these take different times and methods. (pp.70-71).

Consequently what an engineering retraining program needs to do is: develop an experimental, active learning atmosphere with a suitable learning method and standards

of performance; provide guidance for participants; and provide a sequential learning materials (modular courseware) because there are different levels of learning and people learn differently and need different times and methods.

Past learning experience. Many engineers who attend a retraining program and many retraining instructors graduated from college in the 1970s and 1980s, when the Personalized System of Instruction (PSI) method of teaching was extremely popular with engineering educators (Bordoloi, 1977). According to Bloom's learning theory (1976) learning is nothing but the extent to which a learner has already learned. Since most participants in a retraining program are not seeking another degree but rather want to extend or upgrade their knowledge and skill, it would be important to know how they learned in the past. Consequently, an understanding of the PSI method is beneficial for providers and instructors of engineering retraining programs.

Personalized System of Instruction. In 1968, Fred Keller (1968) initiated a new innovative method of teaching called the Personalized System of Instruction, also known as the Keller Plan. The method is based on B.F.Skinner's (1968) "Operant Conditioning" theory. Skinner's theory is based upon the idea that learning is a function of change in overt behavior. Changes in behavior are the result of an individual's response to events that occur in the environment. Reinforcement is the key element in Skinner's Stimulus-Response (S-R) theory. A reinforcer includes such things as a good grade, a feeling of increased accomplishment, or verbal praise that strengthens the desired response. There are also negative reinforcers or punishments that result in reducing an undesired response.

On the subject of "Operant Conditioning" Higgins (1973) writes: "the teacher

plays the role of an architect and builder of individual behaviors, his blueprints specifying not only which conceptual components to teach but also when to teach them. These components are then arranged into a sequence so that the learner moves step by step through a series of progressive approximations which are required."

In the PSI method, the course material is divided into units, each of which contains a given set of concepts, theories, law, or hypotheses. The student's task is to learn each unit and also to complete each given lesson that has a set of objectives and goals, all within the framework of the instructor's expectations. The whole learning process, however, depends upon the student's ability to understand and grasp a given set of materials and to relate the concepts just learned to the assigned problem for adequate solution.

The popularity of the PSI method is well rooted in the relatively strong individualism of American society in general, and in the engineering workplace and engineering schools as well. In general, there are two types of cultures--individualist and collectivist. According to Triandis, Brislin, and Hui (1988, p.270), "individualism is a cultural pattern found in most northern and western of Europe and in North America. Collectivism is common in Asia, Africa, South America, and the Pacific." According to these researchers, individuals from urban, industrialized, mobile, migrating, affluent environments with much exposure to the mass media are likely to be idiocentric, even if they come from a collectivist culture. An idiocentric individual is defined as one who pays more attention to his or her own needs than to the needs of others. The US is a good example of an individualistic culture.

Cooperative learning. Engineering schools and industries cannot live without each other. Markets dictate the necessity of change in industry and this, in turn, will bring many changes in engineering education. The recognition of team work and communication skills along with another new criterion by industries, again put engineering and technological schools in the position of evaluating and reevaluating their curricula. Accordingly, cooperative learning which many experts in the field of education believe will bring an "active learning" into a classroom, is coming into greater use in engineering education. Cooperative teaching and learning is not a new approach; it was used frequently in the past under many different names such as collaborative, collective, and community learning. Cooperative learning is an instructional method that involves students working collectively to achieve a common goal. In a cooperative learning classroom, teachers structure lessons cooperatively so that students are working together in small groups to accomplish the given task. Through cooperative learning, "students are actively involved in a group: problem solving, planning, complex decision-making, debates, and discussion. Cooperation among students typically results in: (a) higher achievement and greater productivity, (b) more caring, supportive, and committed relationships, and © greater psychological health, social competence, and self-esteem." (Smith, 1995, p.2)

The conceptual approach to cooperative learning is characterized by: positive interdependence; face-to-face promotive interaction; individual accountability/personal responsibility; collaborative skills; group processing. Formal and informal learning groups are two distinguishable types of cooperative method. While the formal type

applies to one class session or multiple- week program, the informal type is for a shorter period of one discussion, problem-solving session, or class period.

Unlike traditional learning where everybody was responsible for his or her individual performance and success, in cooperative learning members of each group are responsible for own and each other's learning, performance, and success. According to advocates of cooperative learning (Johnson, Johnson, and Smith, 1991), in such an atmosphere, students are cognitively, physically, emotionally, and psychologically actively involved in constructing their own knowledge. In fact, the students' involvement in this method of learning is also recommended by the American Psychological Association (APA) as an "effective instruction" for school redesign and reform and recognized as the "opportunities for teacher and peer interactions that engage students' natural curiosity" (1995, p.10).

The new (cooperative) learning method has several advantages over the old (individulistic) method such as: creation of an active and constractivist learning environment, recognition of cultural diversity, and learning by relating instead of memorizing. The major differences between the old and new paradigms are summarized in Table 1 (Smith, 1996, p.12). In spite of the effectiveness of the cooperative method, the majority of present engineering educators, since they themselves learned through the PSI method (Bloom's cognitive entry behavior), have naturally adopted it in their own teaching classroom. Consequently, any departure from the PSI method to a more effective and meaningful method is possible only if engineering faculties learn and accept a new one, such as cooperative learning. But a good number of engineering

educators have not yet been exposed to the new popular method and therefore the PSI method or a modified version of it, remains the main teaching and learning approach in engineering schools at the present time.

Table 1. Comparisons of Old and New Paradigms of College Teaching.

	Old Paradigm	New Paradigm
Knowledge	Transferred from Faculty to Students	Jointly Constructed by Students and Faculty
Students	Passive Vessel to be Filled by Faculty's Knowledge	Active Constructor, Discoverer, Transformer of Knowledge
Mode of Learning	Memorizing	Relating
Context	Competitive/Individualistic	Cooperative Learning in Classroom and Cooperative Team Among Faculty
Climate	Conformity/Cultural Uniformity	Diversity and Personal Esteem/Cultural Diversity and Commonality
Relationships	Impersonal Relationship Among Students and Between Faculty and Students	Personal Transaction Among Students and Between Faculty and Students
Faculty Purpose	Classify and Sort Students	Develop Students' Competencies and Talents

Teaching Assumption	Any Expert Can Teach	Teaching Is Complex and Requires Considerable Training
Power	Faculty Holds and Exercises Power, Authority, and Control	Students are Empowerers; Power is Shared Among Students and Between Students and Faculty
Ways of Knowing	Logico-Scientific	Narrative
Epistemology	Reductionist	Constructivist

People's behavior shows how they interact with the world and consequently how they learn. These characteristics reflect specific mind-qualities which "merge as dualities--abstract and concrete perception, sequential and random ordering, deductive and inductive processing, and separative and associative relationships" (Gregorc,1979, p.19). Therefore, to present a comprehensive study on how engineers learn, it is necessary to investigate their mind-qualities--to find out their perceptions about the world, the way they think and their reasoning process, the way they approach and solve a problem, and the way they communicate and work with people. Not much research has been done about engineers' characteristics, but some valuable and interesting studies have been conducted about engineering students. Since engineering students are indeed engineers-in-training and many engineers' characteristics develop during their college years, the conclusions of these studies are relevant here.

Learning preferences. People learn differently and several learning styles exist among them. The Index of Learning Styles (ILS) is an indicator that demonstrates the learning styles of people on four scales. These scales were created and developed by Felder and Silverman (1988). They are: Active/Reflective, Sensing/Intuitive, Visual/Verbal, and Sequential/Global. The first two scales are actually adopted from Kolb's learning styles model (Kolb, 1984) and Jungian theory (Jung, 1971), as described in Meyer-Briggs (1985). During 1992-1996, 858 engineering students at the University of Western Ontario (UWO) responded to twenty-eight forced-choice questions of ILS (Rosati, 1996). The results of the study are summarized below.

1. Active/Reflective index of ILS. Active learners are those who understand and preserve information better by doing something with it--discuss it, explain it, or apply it. In other words, these are the "learning by doing" types of people. On the other hand, reflective learners are those who need time to think when they want to understand or take in information. The UWO study shows that engineering students are typically more active learners and the percentage increases as they move from freshman to senior year (when it reaches 72%). Engineers as active learners tend to take in just enough information to do or make something, and their attitude is, "Let's do something. If it works, fine. Otherwise, modify it and try it again." Of course, a lack of modeling in most American engineering schools promotes this attitude. This approach, indeed, is more popular in defense-related industries, where time and money are not an issue and as long as the built product performs well in the field. As Gerstl and Hotton (1996, p.6) indicate: "it is mainly in military engineering that the engineer is freed from the task of

compromising between technical and economic requirements, because here it is usually a case of meeting performance requirements at any cost." Obviously, this trend in the engineering field may diminish as a result of reductions in the defense budget.

2. Sensing/Intuitive index of ILS. This index refers to how people become aware of and collect information. Sensing people tend to focus on facts and procedure. They are practical types of people and enjoy details, experiences, and well-learned routines but get anxious about new complexities. Intuitive people, on the other hand, are those who prefer to focus on meaning and possibilities and who trust their inspiration to help them deal with increasing complexities. They are imaginative people who respect ideas, concepts, and theory. The UWO study shows 59% of freshmen and 58% of seniors engineering students are sensing types; the engineering students' attitude toward collecting information does not change during their college years. It appears that the technical fields attract a slightly greater percent of sensing types of people than intuitive types.

3. Visual/Verbal index of ILS. Visual learners understand and maintain information better through visual presentation such as diagrams, pictures, graphs, and flowcharts. By contrast, verbal learners prefer written and spoken presentation of a subject. According to the UWO study, 78% of freshman and 81% of senior engineering students are visual types. These high percentages of visual learners among engineering students are rooted in the nature of engineering work. Engineering is basically a pictorial field of study in which diagrams, schematics, formulas, flowcharts, and most recently animation play an important role in presenting or solving problems.

4. Sequential/Global index of ILS. Some people learn better through a linear,

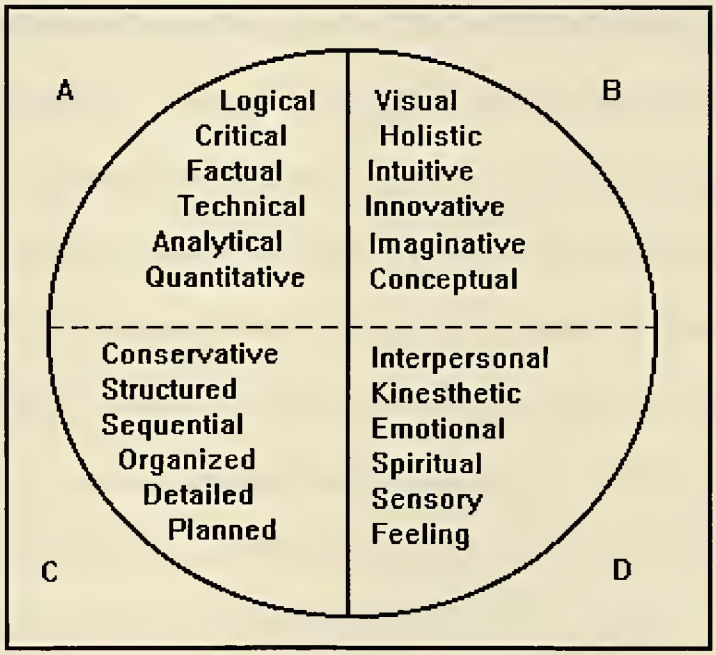
orderly process, and in small, incremental steps; these are sequential index types, and they tend to think convergently in a logical order of progression. Global types learn better through a holistic picture and in large leaps. The responses of freshmen and senior engineering students at UWO show that 69% and 63% of them are sequential, respectively. The study also shows that engineering students think and act globally as they obtain more education and experience.

According to the Index of Learning Styles, which divides learners into four categories-- active/reflective, sensing/intuitive, visual/verbal, and sequential/global-- engineering students are typically more active, sensing, visual, and sequential (ASVS) types of learners. The ASVS types of learners are those who understand better when materials are delivered by facts in a pictorial and experimental format. They prefer detailed explanation in a linear, orderly, and incremental procedure.

Thinking preferences. Most people have multiple primary thinking preferences. To investigate how engineering students think and what their thinking preferences are, the University of Toledo conducted a study during 1990-1994 using the Hermann (1988) Brain Dominance Instrument (HBDI). Ned Hermann is the father of brain dominance technology and the inventor of HBDI. The HBDI divides the relative preferences for ways of thinking into four different modes based on the task-specialized functioning of the physical brain. The HBDI's four modes are as follows: Quadrant A, which refers to left-brain and cerebral thinkers who are analytical, logical, and quantitative types of people. Quadrant B, which refers to left-brain and limbic thinkers who are sequential, organized, planned, detailed, and structured types of people. Quadrant C, which refers to right-brain

and limbic thinkers who are emotional, interpersonal, sensory, kinesthetic, and symbolic types of people. Quadrant D, which refers to right-brain and cerebral thinkers who are visual, holistic, and innovative types of people. Figure 3 Shows Hermann's model of thinking preferences.

Figure 3. The four-quadrant brain model of thinking preferences developed by Ned Hermann.



The responses of 1629 freshmen engineering students at the University of Toledo show they are primarily quadrant A types of thinkers. Their other thinking preferences are B, D, and C, in that order. That is, they tend to be more factual, logical, analytical, quantitative, technical, less interpersonal, emotional, spiritual, sensory, and feeling types

of people. Senior engineering students show almost the same percentage in quadrant A, but they have a lower percentage in quadrant B and higher in quadrant D.

During 1990-1994, at the time the engineering students were taking the HBDI test, a new, innovative course was introduced in the engineering program. The course emphasized a "philosophy of 'zero defects' (no grading on a curve); writing and sketching as thinking tools; teamwork; and applying creative problem solving processes to a design project" (Lumsdaine and Lumsdaine, 1995, p.193). The introduction of the new course may have influenced the statistics. The score of engineering students' preferences in quadrants A and B decreased, while the score in quadrant D increased; there was almost no change for quadrant C. Thus score differences between freshmen and senior on preferences in quadrant B and D may have resulted partly from the new innovative course. In any case, however, the data collected during course of this study shows that engineering students have a strong thinking preference in quadrant A: they tend to be logical, analytical, and quantitative types of people who like to deal with real things and in a technical manner. Tables 2 and 3 show HBDI average profile score for freshman and senior engineering students at the University of Toledo.

Table 2. The HBDI average profile scores for freshman engineering students at University of Toledo.

Profile Scores per Quadrant					Number of Students
Year	A	B	C	D	N
1991	91	80	52	66	91
1992	88	82	52	57	44
1993	86	78	54	72	57
1994	88	74	53	75	30

Table 3. The HBDI average profile scores for senior engineering students at University of Toledo.

Profile Scores per Quadrant					Number of Students
Year	A	B	C	D	N
1991	85	75	55	73	332
1992	84	75	56	70	442
1993	87	74	54	70	415
1994	86	75	55	72	440

It is interesting to see how the results of this study compare with the findings of the Myers-Briggs study conducted at the University of Florida in 1976 (presented in Chapter One). It is also interesting to note that the twenty years elapsed between these two studies does not significantly change engineering students' preferences for learning

and thinking.

HBDI also has some generic profiles such as "1231" which refers to a type of person whose scores of thinking preferences are, in this case, 66 or more, 34 to 65, less than 34, and 66 or more, in quadrants A, B, C, and D, respectively. The results of generic profiles show that engineering students--especially male students--have less thinking preference in quadrant C than in any other quadrants. This finding indicates that engineering students "tend to feel uncomfortable when they have to interact with others or work in teams" (Lumsdaine and Lumsdaine, 1995, p.196). The highest score in the generic profile study belongs to "1122" for both freshman and senior students which indicates they have same high score in quadrants A and B and average score in quadrants C and D. The lowest average generic profiles differ for seniors and freshmen; they scored 3% for 1211 and 0% for 1222 and 1112 respectively.

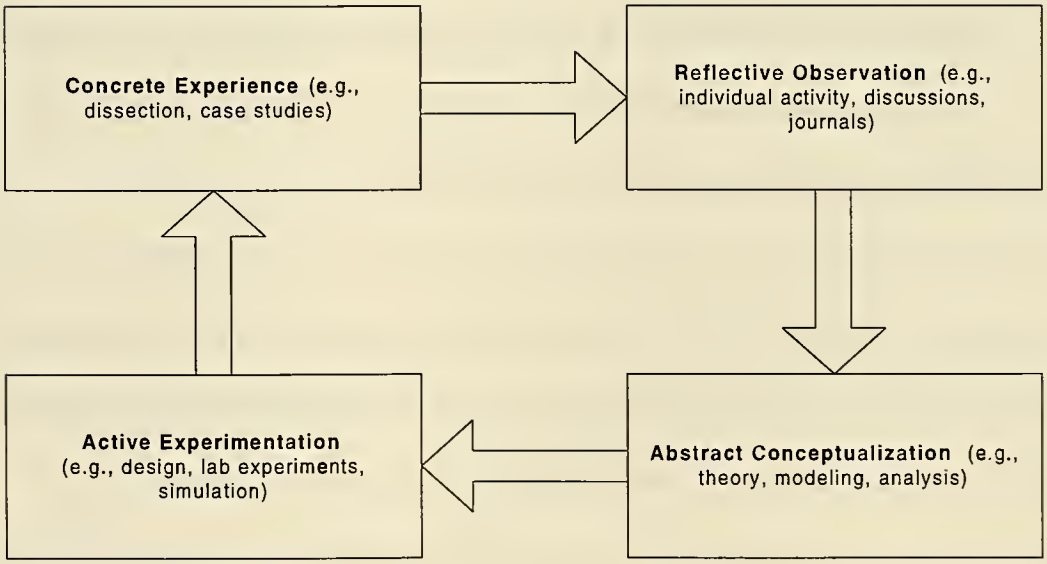
In other words, senior engineering students are not particularly visual, holistic, innovative, imaginative, and conceptual. Moreover, as engineering students move from freshman to senior year, they become more conservative, sequential, and structured in their thinking. This is not appropriate in today's engineering workplace. In fact, in today's highly competitive marketplace, what technical companies are looking for is innovative and creative engineers who can think and see holistically. In recent years, the National Science Foundation has supported many summer workshops for engineering faculty in order to promulgate the concept of innovative and economical design in engineering courses.

In summary, the thinking preferences of engineering students fall into quadrants

A, B, D, and C, in that order. That is, engineers generally are left-brain, logical, analytical, sequential, factual, practical, and structured types of people. At most, about 10% of them have a strong thinking preference in quadrant D which means they are less innovative, imaginative, conceptual, and holistic types. Only a small percentage of engineering students are multi-talented people who have potential to work in a multidisciplinary team.

Preferences for taking in and internalizing. To study how people take in information and internalize it, Kolb (1984) developed an experiential learning model. According to Kolb's model (Figure 4), people prefer "concrete experience" or " abstract conceptualization" when they want to

Figure 4. Kolb's model of experiential learning.


Concrete Experience (e.g., dissection, case studies)
Reflective Observation (e.g., individual activity, discussions, journals)
Active Experimentation (e.g., design, lab experiments, simulation)
Abstract Conceptualization (e.g., theory, modeling, analysis)

take in information. They also learn either toward "active experimentation" or "reflective observation" when they want to internalize information. Based on these preferences, Kolb classified learners in four groups, as follows:

1. Concrete-reflective learners, whose preferences are mainly to derive information through a direct, hands-on, experimental approach. The characteristic question of these learners is "why?" They are simply interested to know *why* they have learn that specific subject. They want to know the relation between the subject and their interest, experiences, and future careers. Only under this circumstance will they respond well to learning a subject. Motivation plays a major role for this type of learner, therefore, they need to be motivated by the teacher.

2. Abstract-reflective learners, whose major concern is "what?" They respond well if the teacher presents the subject in an organized and logical way and if they are given enough time for reflection. Abstract-reflective people are those who seek out a knowledgeable teacher and who prefer to obtain information from an expert.

3. Abstract-active learners, who prefer to have opportunities to perform actively on well-defined tasks and to learn by trial-and-error in an environment that allows them to fail safely. The major concern of this type is "how?" They like to have guidance, a person who can provide them feedback; therefore, they regard teachers as facilitators.

4. Concrete-active learners whose characteristic question is "what if ?" This type of learners likes to apply the learned subject to new situations in order to solve a real problem. These are the learners who want to discover things by themselves. They like to see teachers as initiators who let them test, analyze, practice, and learn by themselves.

Traditionally, many engineering faculty prefer to give lectures in a structured, highly organized, and logical format. (Stice, 1987), (Harb, Durrant, and Terry, 1993). This method of teaching may explain why engineers seek an expert (as described in Chapter One) when they are faced with a problem of needing information. When it comes to an uncertain situation, many engineers often say "let us do it and see what happens" because they prefer to test, analyze, and practice by themselves to learn how things work. In other word, they have a tendency to learn by the "trial-and-error," therefore, many engineers are "active" types of people when they want to learn. On the other hand, engineers are "reflective" types of people when they come to difficulties and seek an appropriate answer.

Reasoning Preferences. Engineering is a logical, analytical, and practical field; consequently, the reasoning process plays a crucial role in accomplishing a successful engineering task. For centuries, deductive and inductive reasoning were two processes of reasoning in a logical field. Deductive reasoning applies to the process in which one can reach a conclusion from relatively general statements that are assumed to be true. Syllogism is an example of deductive reasoning in which conclusion is derived from major and minor premises (Ennis, 1969). On the other hand, inductive reasoning is the process in which one could come to a relatively unrestricted generalization based on some particular facts which are derived from an experience. Analogy or correlation is an example of inductive reasoning in which conclusions of particular cases are followed by observations of some other particulars. Scientific reasoning, which indeed is a product of advancement in science and technology, employs both deductive and inductive reasoning.

Some (Kneller, 1966) believe knowledge is best advanced under scientific reasoning. Deduction is the favorite process of reasoning among educators and "if a person randomly chooses and observes classrooms in institutions of higher learning today, it would appear as if proponents of the deductive method have won" (Miertschin, 1983, p.148).

A typical approach in an engineering project or problem has five steps: "define it, use fundamentals to analyze and understand it, determine and evaluate possible solutions, implement the best, and repeat these if probable gain seems worth the cost in time and effort" (Campbell Martine, 1993, pp.25-26). This method of deriving the best possible solution based on defined criteria through an analysis simply supports the argument of domination of deductive reasoning in higher education including engineering study. Although Miertschin (1983) and Miyara (1992) describe the above steps in different formats:"state new engineering/scientific principles, write equation describing the principles, and provide examples and counter examples of how the principle and equations might be applied in a number of setting" and " foundations, formalization, extensions to the theory, or applications to other branches" respectively, both of them call it deductive method of reasoning.

To furnish American industries with high quality engineers who will able to make challenging state of the art products for the intense competitive global marketplace, engineers need to employ both methods of reasoning. In other words, in the process of transforming a scientific idea to a working model (engineering), engineers need to learn how to apply scientific reasoning in their approach of problem solving.

Summary: Learning is truly a complex process which involves many issues such as

learners' characteristics, past learning experience, and method of instruction. The participants of retraining programs are adults and adult people have a deep need to be self-directing; therefore, the role of the teacher is to engage in a process of mutual inquiry with them rather than to transfer his or her knowledge to them.

Since most participants in a retraining program are not seeking another degree but rather want to extend or upgrade their knowledge and skill, knowing how they learned in the past would be important. In fact, Bloom's learning theory supports this idea and states that learning is nothing but the extent to which learner has already learned. The Personalized System of Instruction (PSI) is the post learning experience for most engineers. In the PSI method, the course material is divided into units, each of which contains a given set of concepts, theories, laws, or hypotheses. The student's task in this method is to learn each unit and to complete each given lesson that has a set of objectives and goals, all within the framework of the instructor's expectations.

Engineers are more "active" learners who often take in just enough information to do or make something in a "trial-and- error" procedure. The engineering retraining program must be designed in a clear and explicit manner and avoid the ambiguous and non-practical lectures. On the contrary, engineers are more "reflective" when they come to difficulties and seek an appropriate answer. Engineers learn better if the training program comes along with practical and experimental sessions. They are visual types of people and understand and maintain information better if diagrams, pictures, graphs, and flowcharts present the subject.

To assist the retraining engineering program to accomplish its desire goal,

materials should be presented in a logical, analytical, and quantitative format, because engineers have a strong thinking preference in quadrant A. Quadrant A is one of the four quadrants in the brain model of thinking preferences developed by Ned Hermann.

Deductive reasoning is a dominated process of reaching conclusions in engineering education. Nevertheless, to educate engineers for the twentieth first century, educators must teach engineering students both inductive and deductive reasonings. In other words, engineers have to come to conclusions based on scientific reasoning, which is the employment of deductive and inductive reasoning, and an effective retraining program must adopt it fully.

Chapter Three

WHY ENGINEERS NEED TO LEARN

> Knowledge has become the only source of
> long-run, sustainable competitive advantage.
> Lester Thurow, The Future of Capitalism, (1996).

The common expression among engineers is "engineers solve their problems and put themselves out of job; economists never solve economic problems and have life time employment. In employer's view engineers are a commodity that they are hired and fired whenever employers need or do not need them" (Trick, 1994, p.60).

Along with cyclical and non-cyclical recessions, cutbacks in the defense budget, frequent downsizing, mergers, and reductions in government spending on research and development, and declines in permanent employment placements have put thousands of engineers out of work. In this situation, engineers have no recourse but to learn continuously. Massive lay-offs of engineers in the late 1980s and early 1990s, with an 50-year high unemployment rate of 4.08%, are not the only factor putting lifelong learning on engineers' agenda. Maintaining their present position, in the face of rapidly changing technology that becomes obsolete ever more frequently, is possible only by continuous upgrading of their knowledge and skills.

In such a competitive engineering job market, employers tend to hire, promote, contract, and work with the most highly-qualified certified or licensed engineer. In January 1994, the National Society of Professional Engineers proposed a new model for engineering licensure. Under the new model, mandatory continuing education is a

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requirement for the renewal of a Professional Engineer (P.E.) license.

Unemployment and temporary placement. Social and political changes around the world in recent years have had their own special effect on the economy. For example, the end of the cold war destroyed the rationale for a large defense industry. This coincides with, and amplifies, the recession in civilian economies. Changes in the economy and intensification of world competition as a result of saturated domestic markets and the influx of newcomers to the international markets, have had a serious impact on the technical workforce. The earmark of the new economy is flexibility in response to the needs of the marketplace, and this in turn requires flexibility in the workforce, which means less permanent employment. In this regard, Carnevale states, "The characteristic signature of the new economy is flexibility. The fast pace of change within networks and the volatility of markets, especially global markets, requires flexible responses. Flexible institutions need flexible workforces. Most employers have reacted by building a workforce in layers: a core workforce with permanent status and a peripheral workforce of part-timers, temporaries, consultants, and suppliers who are accorded varying degrees of commitment" (Carnevale, 1991, p.139).

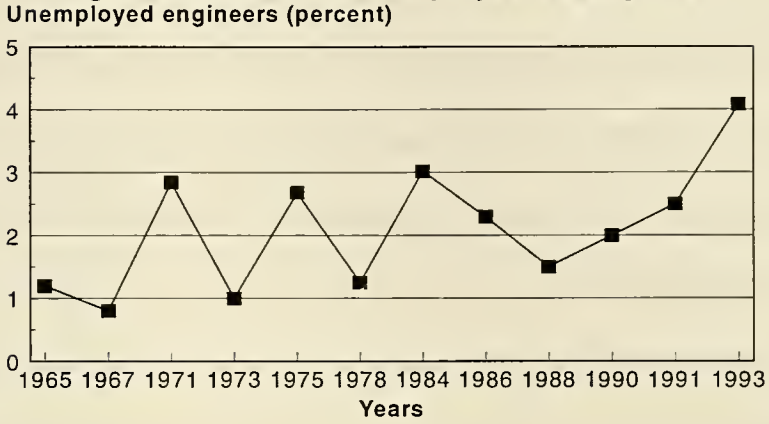
To adapt to the recent social and economic changes, American "companies resorted to a range of cost-cutting strategies, the hitherto sacrosanct ranks of managers and professionals were not spared. The actions have varied from massive terminations to retraining and redeployment, from 'resizing' to 'restructuring' (Doeringer, 1991, p.156). Unlike the cyclic economy variation, the restructuring of American companies in either the manufacturing or the service sectors has affected not only blue collar but also white

collar workers such as engineers. According to the National Society of Professional Engineers, "the engineering specialties most adversely affected by the slow economy and lower defense budgets are electrical-electronic, industrial, and aerospace. Job losses among these categories amounted to an estimated 41,000, 25,000, and 23,000 respectively, between 1987 and 1992" (NSPE, Online).

The restructuring of American industry. At the end of the 20th century, the whole world is currently experiencing major social, political, cultural, and economical changes. A forty years of global military confrontations are replaced with economic confrontations and like any other phenomenon, the new economy has its own characteristics. According to Carnevale, "the emerging new economy retains the volume and productivity standards of mass production and marries them to the craft standards of quality, variety, customization, convenience, and timelessness. A notable difference is that autonomous artisans and anonymous mass production works are replaced by interdependent work teams" (Carnevale, 1991, p.91). In other words, teamwork and a new class of production--that is, lean production instead of mass production--are the most significant characteristics of the new economy.

In this new wave of change, engineers from all industries, and from defense-related industries in particular, have felt the squeeze. In 1993, engineering unemployment in the United States rose topped 4% (Figure 1).

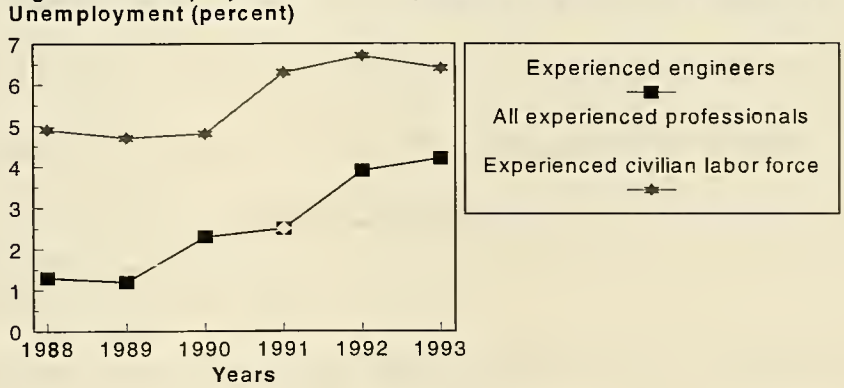
Figure 1. Percent of unemployed US engineers



Source: Engineering Workforce Commission, American Association of Engineering Societies

Despite a decline in the unemployment rate for experienced civilians from its peak in 1992, the unemployment rate engineers has not changed significantly, since many of them, especially older ones, have moved to some other profession (Figure 2). Actually, based on the Bureau of Labor Statistics' definition, an engineer who takes a non-engineering job is not an engineer; and if he or she gets laid off then that person is

Figure 2. Unemployment within experienced US workforce, 1988-1993.



Source: Bureau of Labor Statistics; Vin O'Niel, IEEE US Activities Board

not an unemployed engineer. In fact, according to the Institute of Electrical and Electronic Engineers (IEEE) Manpower Committee, "the number of displaced engineers is at least twice as great as the number of unemployed engineers" (Bell, 1993, p. 20). Many of these displaced engineers cannot get their engineering jobs back, simply because those jobs no longer exist. Also many engineers who lost their jobs in the recent economy fluctuation may not able to be re-employed again in their area of expertise, simply because those types of job are either squeezed, moved to other country, or eliminated altogether. According to Trudy E. Bell (1993), the senior editor of "Spectrum," the Journal of the Institute of Electrical and Electronic Engineers (IEEE):

> "The current huge layoffs are not just the belt-tightening response of many companies to cyclical hard times. On the contrary, the layoffs are the most visible--and painful--symptom of fundamental and permanent structural (non-cyclical) change in the way high-tech companies will conduct business in the 21st century. Thus, many of those former employees--including the engineers--may never get their jobs back even once recovery is fully under way, because those jobs will no longer exist."(p.18).

Unlike other cyclic recessions, many factors such as economical, social, cultural, political, historical, and technological factors have played a role in the recent recession. The following are among those that have particularly affected the massive lay-offs of engineers and have influenced the demand for engineers in almost every industry from manufacturing to the service sector.

The end of the cold war. After approximately half a century of cold war, the US government has finally begun to bring about deep cutbacks in the defense budget and military expending. The electronics industry has experienced the greatest lost from

declining in military spending in recent years. For example, in 1992 alone, about 4.1% of 2.39 million of the US electronics industry employees lost their jobs (Table 1). The decreased spending of $36.6 billion in 1997 for "research, development, testing, evaluation, and other critical accounts for the electronics industry," is expected to drop to an even lesser amount of $35.5 billion for 1998 and will probably continue to drop to $32.9 billion in 2001 (Rhea, 1997, p.1). The diminishing of the huge military market for the electronics industry has promoted them to turn to the commercial market and abandon military business. In the beginning of 1997, Intel Corporation joined some other electronics companies such as Motorola Semiconductor and Advanced Micro Devices which "have abandoned the military market in recent years" (Keller, 1997, p.1).

Table 1. US electronic industry employment.

Industry	December 1991	December 1992	Change
Computers	463,421	436,635	- 5.8 %
Semiconductors	255,035	250,949	-1.6%
Prepackaged software	151,409	153,679	+ 1.5%
Communications equipment	276,600	267,406	- 3.3%
Computer programming	193,518	184,097	- 4.7%
Instruments	342,089	323,702	- 5.4%
Defense, commercial guidance systems	286,474	256,170	-10.6%
Consumer	68,327	67,419	-1.3%

Industry	December 1991	December 1992	Change
Other components	351,850	350,488	-0.4%
Total employment	2,388,723	2,290,545	- 4.1%

Source: American Electronic Association

The massive lay-offs of defense engineers in recent years are simply part of a new era in human history. In 1991, the US military-industrial complex employed a total of some six million people, on active duty in the military services, in the civilian ranks of the Department of Defense, and in the private defense industry (Tables 2).

Table 2. Technical (including engineering) Jobs lost in the United States, 1991-1994.

When	Organization	No. of Jobs Lost	Reasons
1992 - 5/1993	Amdahl Corp.	2,000	Recession
1992-96	Bellsouth Corp.	8,000	Competition
1/1993-mid 94	Boeing Co.	28,000	Downsizing/Cut in military spending
1993	Comm. Edison	2,125	To reduce cost
1992-93	Digital Corp.	27,700	Downsizing
1993	GE Aircraft Engines	5,400	Cut in civilian and military spending
1993-95	General Motor Corp.	74,000	Restructuring/Competition

When	Organization	No. of Jobs Lost	Reasons
5/1993	GTE Corp.	6, 400	To reduce cost
1992-93	IBM Corp.	90,000	Recession/Downsizing
1993	McDonnel Douglas	8,700	Cut in civilian and military spending
1993-97	NASA	5,000	Budget reduction
2/1993-1995	Nigara Mohawk	1,400	Competition/To reduce cost
1993	Northrop Corp.	2,400	Cut in civilian and military spending
1991-92	Nynex Corp.	3,400	Competition/To reduce cost
1993-1994	Pratt & Whitney	9,000	Cut in civilian and military spending
1993	Textron Inc.,	1,900-2,200	Cut in civilian and military spending
1992-1993	Thiokol Corp.	2,944	Competition/Budget reduction
1991-1992	United Technologies	26,000	Cut in civilian and military spending
1993	Western Electronic	4,360	Cut in civilian and military spending
1991-92	Westinghouse	4,000	Cut in civilian and military spending

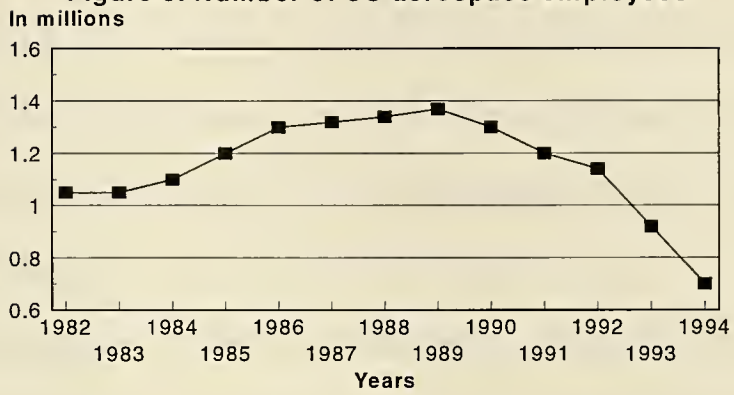
Source: Spectrum, August 1993

In 1992, U.S. Congress Office of Technology Assessment predicted as many as 1.1 million of 6 million jobs in the U.S. defense industry could disappear by 1995. In

1991, the US defense spending was about $287.5 billion that provided work for nearly six million people. In 1995, with lower defense spending--about $253.7 billion--the rate of unemployment in the defense-related companies reduced to approximately 4.9 million. By year 2001, an estimated 3.5 million jobs will remain in the defense industry as a result of faster reduction in defense spending--about $168.6 billions.

According to the annual survey of the Aerospace Industries Association (AIA), fully a third of aerospace jobs have disappeared since 1989, with 13% lost in 1993 alone and an additional 5% lost in 1994 (Figure 3). Huntsville, Alabama--the home of the U.S. Army's Red stone Arsenal, NASA's George C. Marshall Space Flight Center, and hundreds of high-tech companies--is among those places that have been severely affected by the double blow of cutbacks in both defense spending and NASA's space station project. As a result, between 3,000 and 6,000 engineers lost their jobs in Huntsville alone. In 1993, an estimated 250 high-tech companies operating within the Cumming Research Park lost 3,500 out of 22,000 jobs. In late 1990 and early 1991, Mitre Corporation one of the largest companies in the field of communication, began laying off and offering early retirement to approximately 12% of its engineers in Colorado Springs, Colorado. In 1993, while the media quoted economists and announced the end of the recession and beginning of recovery, the aerospace company Pratt & Whitney in Connecticut laid off 7,600 of its employees (Bell, 1994). Most of these high-tech companies

Figure 3. Number of US aerospace employees



Source: Aerospace Industries Association

Globalization of economy and work. The restructuring of industrial organizations and the downsizing or right-sizing of the workforces are, indeed, international phenomena. Many large and high-tech corporations are multinational; therefore, lay-offs in the workforce of one nation may fuel lay- offs in other countries. For example, half of the IBM employees who have lost their jobs worked in Europe and Asia. In the US, Europe, Japan, and Canada, the decline in engineering jobs is directly related to multi-nationalization of companies, especially in the high-tech areas. American engineers lose their jobs because they have to compete with "world-class engineers [who] are being trained and put to work in countries like Brazil, India, and Korea... programmers in the United States are competing with people in South Asia who sit in front of Sun work stations, linked to consumers of their product by modems" (Engineering Workforce Commission, 1994, p.13). The following figures about engineering jobs lost in Canada, Germany, and the United Kingdom give a better picture of the globalization of work and

the economy.

1. More than half of Canadian engineers work in the province of Ontario and, as of December 1992, about 2.5% of them were unemployed. The previous high percentage of unemployment among engineers in the province was about 1.8%, at the depth of the 1982-83 recession. (Bell, 1993).
2. Approximately 1.7 million of the registered unemployed workers in the eastern part of Germany are non-labor professionals. About half a million of these people are in full-time training programs, 300,000 are in job creation programs, and 837,000 are on early retirement pensions. In 1992, a total of 44,742 engineering job-openings were advertised in Germany, which is down 12% from 50,627 in 1991 (London's Financial Times, Nov. 5, 1992).
3. According to the Engineering Employers Federation in London, approximately 300,000 engineering jobs have been lost in the United Kingdom since the end of 1989 (Bell, 1993).

Shift from large to small companies. The most significant move in American companies in recent years is the fundamental change in organization, from large vertical to small horizontal companies. "In essence, they are downsizing themselves into relatively small entities, concentrating on their core businesses, and subcontracting everything else. Thus, they no longer need as many employees as before, nor do they need them on as steady a basis" (Gracon, 1992, p.63). As a result of the changes in organization, an estimated six million jobs were eliminated by American companies during the late 1980s and early 1990s. An average of about 3,100 members of the

workforce were laid off per day by large company in the first quarter of 1993 (DuBrin, 1995). Most of the jobs lost in this period were in middle management; considering the fact that middle management in the technical workplace consists mostly of engineers, it can be seen that the actual unemployment rate for engineers is much higher than the official figure of 4%.

Although all size of American companies--from large to small size--trimmed down their workforce in recent years, hundreds of small high-tech companies have grown, hiring even as big firms were laying off. In fact, as Doeringer's study of 1,100 companies shows, the percentage of downsizing declines with size of company (Doeringer, 1991). Table 3 shows downsizing among US companies by their size and sector in 1987.

Table 3. Downsizing among US companies, by company size and sector, 1987

	All companies	Company size			Industry	
		Large	Mid-size	Small	Manufacturing	Service
Downsized during past 18 months	45%	58%	49%	40%	57%	43%
Expected to downsize during next 18 months	17%	34%	19%	11%	16%	19%

Source: American Management Association, 1988

The success of smaller over larger companies is rooted in their less bureaucratic

organization and their flexibility toward market demands. In other words, "smaller companies, with their leaner management structures, niche markets, and faster innovation, have been more responsive to market changes and have had lower overhead costs" (Bell, 1993, p.19). Consequently, they have shown better and healthier growth than larger companies. To become more flexible and responsive to markets, some large companies such as IBM Corp. and General Electric Co. are in process of de-centralizing their organizations by restructuring themselves into independent business units.

According to the Corporate Technology Information Service Inc., employment at the smaller high-tech companies had expanded at an average of 1.2 % since June 1992 and created 16,677 new jobs (Corp Tech, 1992). At the time of expansion of employment at smaller companies, mid-sized and large companies laid off thousands of technical workforces including engineers. Table 4. shows the growth of the US small high-tech companies.

Table 4. Growth of US small high-tech companies.

	No. of firm	No. Of jobs		
		June 1992	June 1993	% change
Biotechnology	129	9,938	10,696	7.6
Medical	195	15,572	21,038	7.5
Computer software	988	40,700	43,600	7.1
Pharmaceuticals	63	8,294	8,722	5.2
Chemicals	123	12,891	13,290	3.1
Advanced materials	218	26,791	27,017	0.8
Enviromental	256	26,684	26,874	0.7

	No. of firm	No. Of jobs		
		June 1992	June 1993	% change
Test measurement	396	37,390	37,585	0.5
Holding companies	213	38,143	38,218	0.2
manufacturing	431	41,618	41,564	-0.1
Telecommunication	271	28,562	28,469	-0.3
Computer hardware	566	41,477	41,075	-1.0
Energy-related	153	16,968	16,685	-1.7
Transportation	103	16,409	16,014	-2.4
Factory automation	369	36,544	35,466	-2.9
Subassemblies, components	630	73,986	71,563	-3.3
Lasers optics	186	14,708	14,054	-4.4
Defense-related	60	9,182	8,770	-4.5

Source: Corp Tech, 1992

As Table 4 indicates, smaller companies especially in biotechnology, medical, and computer software grow at a fast rate, despite the overall shrinking picture in US engineering employment among defense-related companies. In fact, high-tech companies in medical, biotechnology, information technology, and non-defense or dual use (defense and non-defense) technology have much clear picture for future growth and profite. Consequently, these are the area that engineers have to focus on.

A better gain in profitability among smaller companies in the US has inspired medium-sized and large firms to reshape the structure and size of their organizations. As a result, down-sizing or right-sizing has taken place in medium and large companies in

order to stay competitive in today's intense global markets. For example, the following lay offs occured in 1993 within leading high-tech large companies:

IBM Corporation 90,000.

General Motors 74,000.

Boeing Corporation 28,000.

Digital Equipment Corporation 27,700.

United Technologies 26,000.

Change in the organization of production. Traditional mass production in the United States and European countries was organized on a hierarchical and bureaucratic basis which has resulted in expensive and slow production. By contrast, the Japanese mode of production, which is called "lean production" has resulted in swift production along with a lower cost in both assembly and process industries. The advantage of the Japanese mode of production lies in a combination of total quality control, flexibility, just-in-time logistics, total asset productivity, reduced cycle times, concurrent engineering, and continuous improvement. To explore Japan's success, most U.S. and European large manufacturing companies have fundamentally restructured their entire production process, from design through assembly and distribution, in the last decade or so. The aim of this conversion is simply an adoption of the lean production philosophy.

Although adoption of Japanese manufacturing innovation has resulted in cost-effective production, it has also resulted in tremendous lay-offs in U.S. manufacturing companies. According to statistics published by the National Society of Professional Engineers, as a result of changes in modes of production and also some other factors such

as saturation of the domestic market, 13,000 industrial engineers lost their jobs between 1989 and 1992. This figure is the largest absolute decline of any engineering speciality (NSPE, Online).

De-industrialization process. Maintaining a cost-competitive product in today's intense global market is a key factor for both competition and survival. It was always easier and economically less expensive to move and conduct business in an area with lower labor cost. In fact, the trend of the de-industrialization process--the relocation of industrial plants to take advantage of low-cost labor and materials--has grown rapidly in advanced western countries in the last decades. According to the Engineering Workforce Commission, (1994, p.13) "Not just labor but work itself now migrates across national borders, through plant relocations, outsourcing to foreign contractors, and the use of international communication networks to reach work sites around the globe." In the US, several companies such as AT&T, Bendix, Corning, Data General, Digital Equipment, Ford, Whirlpool, and Zenith have set up manufacturing plants in a 500-kilometer-wide belt south of the border in five northern states of Mexico. In Europe, Germany is the most expensive place to do business, right after the United States and Japan. As a result of high labor-cost and tax rates (50%) for top corporations, more than half (55%) of all major German companies such as Benz, Bosh, and Siemens have moved part of their production abroad (Bell, 1993).

China and India, with their new policy for foreign investment that offers tax breaks and other incentives to employers, have attracted many American companies such as Digital Equipment Corporation and Hewlett-Packard Company. Both Chinese and

Indian well-trained engineers, who work at American electronics and computer companies in their own home countries, are paid much less than assembly workers in the US. Consequently, as a result of the new wave of de-industrialization, not only workers but engineers have lost their jobs.

Automation and information technologies. The first generation of automation that took place in manufacturing has both increased productivity and put many workers out of jobs. By advancing in both hardware and software engineering, the new generation of automation puts even higher-level skilled workers such as engineers in jeopardy. The adoption of automation and the use of information technology is popular in American companies because of its efficient and cost-saving nature. In this regard, "a survey of 400 large companies from 1987 to 1991 shows that the annual return on their investment in information systems has averaged 54 percent for all businesses (Brynjolfsson and Hitt, 1992). Table 5 shows the use of automation technology in small and large companies in the United States.

Table 5. Use of automation technology in small and large companies in the US.

Equivalent types of new manufacturing technology	Small company (percentage, %)	Large company (percentage, %)
Computerized Numerically Controlled (CNC)	39.6	69.8
Flexible Manufacturing System (FMS)	9.1	35.9
Computer-Aided-Design/Engineering (CAD/CAE)	36.3	82.6

Equivalent types of new manufacturing technology	Small company (percentage, %)	Large company (percentage, %)
Automated guided vehicles	0.8	13.1
Automated inspection, final product	10.5	44.3
Automatic storage and retrieval	5.5	43.3
Pick-and-place robots	1.9	24.4
Other robots	3.9	35.0

Source: Manufacturing Technology, 1989 and Current Industrial Reports SMT,1988.

However, the higher percentage of return on investment and the improved efficiency in the manufacturing process, from design to production, shows only the good side of automation. The other side of automation is the elimination of many jobs from production to service sectors. In fact, automation is a key reason for structural (non-cyclical) unemployment that can be documented in all engineering practices. In the field of electronic engineering, the Electronic Design Automation (EDA) has reduced design, test, evaluation, and simulation time to almost one-fifth of the traditional methods. It also has eliminated many engineering positions in an electronics design team. In civil engineering, "CAD/CAM systems means that one skilled senior professional can accomplish the same amount of work that used to require teams of six to twelve degreed professionals" (Engineering Workforce Commission, 1994, p.10).

The shift from permanent to temporary job placement. At the current rate, it is predictable that technology may change three times over the course of an engineer's career. Consequently, the era of permanent and secure positions for engineers is vanishing

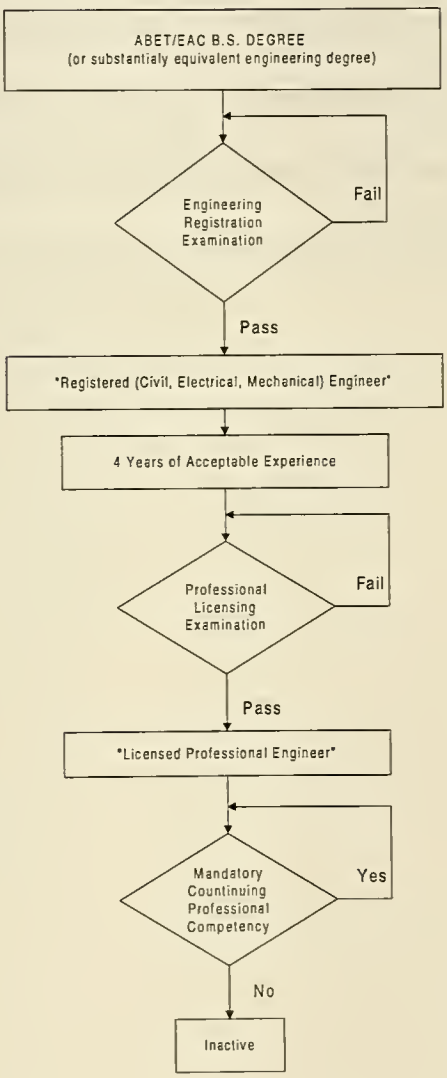
and engineers need to adapt themselves to project or temporary job markets. Some experts predict an even more unpleasant future for engineers. In this regard, Gracon (1992, p.63) states: "people in high-tech areas should plan on an average of only two to three years in any position. After that time, it is likely that the position will either disappear or evolve into something else." If temporary work brings financial hardship for engineers, it is nonetheless a good source of a cheap workforce for companies. The advantage of a temporary position in a company is clear: skilled personnel can be hired only as needed, incurring no permanent overhead benefits. In some states such as California, where firing people without cause is quite difficult, project, half-time, or temporary employees are more attractive to companies.

Requirements for engineering licensure. Since 1907, when Wyoming became the first state to pass legislation governing the practice of engineering, to protect the public health, safety and welfare, all the states have developed different laws and regulations for the practice of engineering. Today, only licensed Professional Engineers (P.E.) may prepare, sign and seal, and submit engineering plans and drawings to a public or private authority for approval. According to a model task force of NSPE, about 350,000 of 1,800,000 U.S. engineers are licensed P.E. In 1994, a task force with representatives from the American Society of Engineering Education (ASEE), the National Council of Engineers for Engineering and Surveying (NCEES), the Engineering Deans' Council (EDC), the Accreditation Board for Engineering and Technology (ABET), and the National Society of Professional Engineers (NSPE) was established to study the new model for the licensure process in order to "increase the number of engineers who become licensed

professional engineers while insuring that the protection of the public is properly maintained" (NSPE, Online).

In addition, the task force proposed mandatory Continuing Professional Competency (CPC) requirements to be met for an individual to keep an active P.E. license. On the issue of mandatory CPC requirements, the task force report states, "At no time in the history of the engineering profession have the technologies associated with engineering changed more rapidly. Just as in the profession of medicine, the professional engineer must commit to a lifetime of learning if he/she is to be at the cutting edge of the profession. Therefore, the task force believes that one of the most important factors related to excellence in engineering service and protection of the public, is to provide a means of assuring that all licensed professional engineers continue to update their credentials throughout their professional lives" (Final Draft II, 1996, p.136). Figure 4. shows the proposed basic model for engineering licensure.

Figure 4. Proposed basic model for engineering licensure



Summary. At the end of the twentieth century, American companies are undergoing restructuring, outsourcing, and downsizing, and the engineering profession is feeling more squeezed than any other profession. Thousands of engineers have lost their jobs in

the last decade. For engineers, the prospect of stable, lifelong employment is a thing of the past. In the future, most engineers will experience several job changes during their career life. This situation in the engineering job markets has developed an intense competition among engineers, and rewards are going to the well-trained and knowledgeable applicants. Therefore, to remain employed or to be re-employed, engineers need to position themselves to adapt to the new situation, if they want to succeed in this ever-changing work environment. The key to success is none other than formal and informal lifelong learning.

Chapter Four

WHAT ENGINEERS NEED TO LEARN

In the middle of 1997 economic indicators are strong, unemployment rate at 4.2% stands at its lowest in the past twenty-five years, and fewer frequent dislocations takes place within major corporations (Industry Engineer, April/May 1997). Although, the National Society of Professional Engineers' Industry Advisory Group forecasted further trims and reorganization of the workforce, the reduction is expected to be less extensive than in the past. Despite all these good news, engineering employment does not appear to duplicate the bright outlook once had in the 1980s. Major companies still insist on the idea of having permanent employees for their core technologies and use contract employees for everything else. Consequently, engineers need to prepare themselves for lifelong education now more than ever before. However, before engineers-employed or unemployed-attend any retraining program for any particular field, they should be aware of the extend of demand in that field in order to avoid further disappointments. John J. Guarrera, the past president of IEEE and director of the Center for Research and Services at California State University, Northridge reports one such situation. He states, "One retraining program moved 20 displaced engineers from defense and aerospace into the new field of ocean engineering....They all finished the contracted program....Their joy was marred by just one serious problem: there were no jobs for ocean engineers. The 20 unemployed aerospace/defense engineers were then reclassified as 20 unemployed ocean engineers." (1992, p. 63). Consequently, it is important to know if there are jobs available

for new skill and knowledge. As discussed in Chapter Three, in 1991, about 2.39 million people worked in the electronic industry and 4.1% or 99,000 of them lost their jobs in 1992. To find out the possible job opportunities in the electronic industry for the next several years, it is worthwhile to explore all major areas of this industry.

Data Communications is one of the fast growing areas in the electronic industry. Asynchronous Transfer Mode (ATM), information superhighway, Universal bidirectional Interactive (UBI) network, Open Systems Interconnect (OSI), Low-Earth-Orbit (LEO) satellites are popular areas in data communications. The UBI consortium (an American and Canadian joint effort) invested $200 million for seven years starting in 1995 to bring national data communication infrastructures to houses. At the present time, the first stage of UBI provides Video way Technology to 350,000 households in North America and London. Besides so many small to large companies such as Cirrus Logic, DigiCash, Netscape, and MCI, several universities such as MIT, University of California at Berkeley, Carnegie-Mellon, Cornell, and Stanford are active in data communications. (Lowe, 1995).

Telecommunications which now employs erbium-doped fiber amplifier and Wavelength-division Multiplexer (WDM), attracts billions of dollars to investment in High-Definition TeleVision (HDTV), wireless telephones, and Personal Communications Service (PCS). In 1994, the Federal Communication Commission (FCC) gave licenses to six companies to operate PCS. These six companies pledged a total of $650 million for the licenses. McCaw Communication Incorporation and AT&T are investing more than $10 billion in digital upgrades of cellular networks (Kobb, 1995). Cellular telephony has

shown tremendous growth around the world (Table 1).

Table 1. Cellular telephony growth from 1993 to 1994.

Markets	January 1993 (in thousands)	January 1994 (in thousands)
North America: 47%	12, 086	17,721
Western Europe: 63%	5,477	8,918
Australia and Asia: 71%	3,404	5,814
South America: 254%	174	600

Source: TeleGeography Inc.

Solid State technology will fall deeper in complex image-processing, graphic circuit, and memories with expansion of multimedia. Low-power design discipline is another important area in solid state. The nonvolatile ferroelectric memory is a new area in solid state technology which is estimated to open a $2 billion market worldwide for their manufacturers--Ramtron International Corporation and Hitachi Ltd. (Geppert, 1995).

Computer and computer related companies still enjoy a strong market for their products. Sixteen and thirty-four million personal computers were sold in the United States and worldwide in 1995 respectively. According to Intel Corporation chairperson, Andy Grove, there will be sales of more than 100 million personal computers worldwide by the year 2000, more than sales of cars and televisions. As long as the computer industry benefits a healthy and stable market, their employees including engineers, feel more job security and enjoy the available job opportunities (Juliussen, 1995).

Power and energy industry may celebrate for the new policies of deregulation and privatization but this celebration does not come with any better picture for hiring and secure employment for their employees (Zorpette, 1995).

Software engineering may have a better future than any other areas in the electronic industry. At the present time, there is a big demand for software engineers in the job markets. Most of the software industry is emphasizing on the object-oriented approach since it is going to be the future of software. Electronic engineers with additional skill and knowledge of software engineering may have the best possible position for secure employment and high salary (Comerford, 1995).

Aerospace and military are still on the declining edge. According to Don Fuqua, president of the Aerospace Industry Association (AIA), the aerospace and military industry face with more competition and partnership coming the from Eastern Europe and former Soviet Union. With all new consolidation such as that of Lockheed and Martin, there are many fewer job opportunities than before (Dooling, 1995).

Biomedical industry is the fastest-growing manufacturing sector in the United States, supplying 49% of the world's medical device requirements (Adam, 1995). In 1993, 324 US medical and biotechnology companies employed 10,696 people with a total of 7.6% more than 1992 (CorpTech, 1992).

Industrial electronics has gone through tremendous changes in recent years. Emerging control technologies such as Mechatronics, a combination of mechanical engineering, electronic engineering and computers, is a whole new area in industrial electronics which has captured a great deal of attentions. Currently, the National Science Foundation (NSF)

supports several engineering schools' coalitions, such as Synthesis (1996), to promote the philosophy of mechatronics and train engineering faculties. Computer Numerical Control (CNC), neural network, and fuzzy logic are also gaining popularity in industrial electronics.

Engineering jobs around the nation. In April and May 1997, an average of 1600 engineering jobs posted each week in the major newspapers in the following ten cities around the nation: Atlanta, Boston, Chicago, Denver, Detroit, Houston, Los Angles, San Jose, Seattle, and Washington, D.C.(online). Approximately, there were about 250 electronic engineering jobs out of 1600. Demand for design engineers especially digital designers were noticeably higher than any other areas. Engineers with wireless communication, analog design, Programmable Logic Controller skill also had a better opportunity to find a position.

Engineers responsibilities have changed over past decades because of social, economical, and organizational changes. At present time, engineers need to take some more multidirectional responsibilities which are "include looking at client satisfaction with the product, design efficiency, innovation, and involvement in professional societies" (NSPE, online). Engineers have also to find out what types of quality for which their employers looking. The following are those qualities that industrial employers describe when they refer to a successful engineer (Industry Engineer, April/May 1997, p.2):

1. Communications and Interpersonal skills. Major corporation want both technical and communication skills. They want all employees to possess

cultural and social awareness.
2. Engineering Science Fundamentals. Employers expect engineers to have good background in physical and life sciences, mathematics, and information technology.
3. Design and Manufacturing processes. Employees have to have good knowledge in design, economy of design, and manufacturing processes.
4. Multidisciplinary, system perspective. Industry operates around system, not disciplines. Engineers must develop a sense of the broader implications of their work, and how it fits the bigger picture.
5. Ethical Standards and Integrity. The increased pressure of competition makes it more important for engineers to have the respect of others in dat-to-day interactions. As organizations become more decentralized, they magnify the importance of honesty and trustworthiness.
6. Commitment to lifelong learning. Young engineers must be aware that they are only beginning their education when they receive their first degree and must develop the habit and ability to learn throughout their career life.

In spite of job opportunity in the marketplace, engineers must learn how to function effectively at the workplace. They must be aware to the changes in technology and at the same time be sensitive and responsive to changes at the work environment and social needs. Effectiveness in engineering practice according to Moore, depends on several issues, such as:

"Subject matter competency and personal and interpersonal process skills, including self-awareness, self-insight, intuition, judgement, creativity, idea-having, frequency and flexibility of thinking, responsiveness, listening and expressiveness. Social and environmental constraints are increasing the need for awareness, sensitivity and creativity in engineering design. Engineers must be prepared to participate effectively in interdisciplinary professional teams and client-consultant relationships. Engineers must learn self-direct their learning process after graduation to keep pace with rapidly changing technology and social needs." (1976, p.120)

Four distinguishing factors exist in Moore's statement: professional competency, creativity in engineering design, awareness about environmental issues, and team work.

Creativity in engineering design is the big issue at engineering workplaces around the world. The better, reliable, cost effective design is the one that pushes the competitor's products out of the market. In many experts' view (Rhyne, 1991) the idea of concurrent engineering is the answer to develop a product that captures the markets. Rhyne argues that:

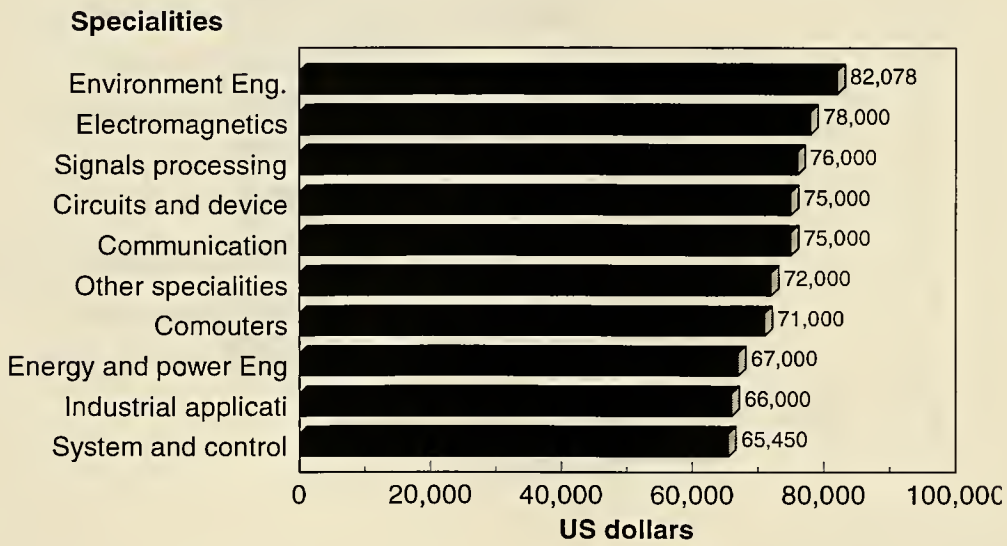
"For the past decade, while the U.S. balance of trade has gotten worse and worse and while non-U.S. products have pushed domestics off most shelves and showroom floors, rumors about the death of U.S. industry have been bouncing around government, industry, and academia like a SuperBall. A root cause for that demise is often cited to be the failure of American engineers to practice the art of design as effectively as their Asian and/or European counterparts. To match them, it is usually suggested that American engineers need to be taught new approaches to the design process, one of which is commonly called concurrent engineering." (1991, p.112)

Nigel Freedman (1994) looks at the above issue differently and he writes about the changing way that technical staff are recruited and trained. To find a desired position, engineers must consider the Freedman's statements as a guideline for recruitment. The following are the Freedman's statements about the new shift in technical staff recruitment:

1. Knowledge to capability.
2. Individual performance to team performance.
3. Depth of knowledge to breadth of knowledge.
4. Stability of skills to flexibility of skills.
5. Product engineering to system engineering.
6. Individual learning to collective learning.
7. Conceptual learning to action learning.
8. Content learning to context learning; i.e, knowing where what we do "fits" within the organization.
9. Results orientation to process orientation; so that success can be rapidly replicated and one can stay ahead of the competition. (1994, p.13).

Engineering salaries. The growth indicator of engineering salaries and fringe benefits is another source that engineers should take under consideration when they plan to refocus their knowledge and skills. Obviously, those areas in engineering which are in demand benefit more from corporate profits. According to IEEE's 1997 survey of engineering salaries and fringe benefits: "Salaries are booming in some engineering fields, while in others, salaries are moving up at a snail's space" (The Institute, May 1997, p.1). In IEEE's survey, the highest percentage growth in salary among the ten different areas in electrical and electronic engineering belongs to electromagnetic and radiation with 18.7%. On the contrary, engineers in system and control had the lowest percentage of salary growth with only 0.6%. Figure 1 shows the median salary for ten different areas in electrical and electronic engineering in 1996.

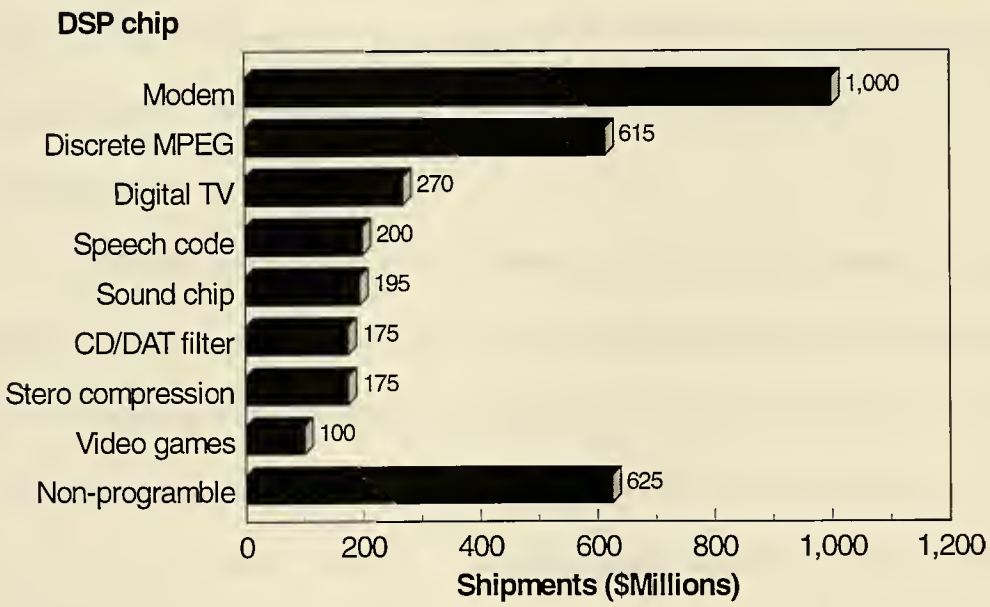
Figure 1. Median 1996 salary by primary area in electrical and electronic engineering.



Source: American Association of Engineering Societies.

As shown in Figure 1, engineers in areas of signals processing, circuits and device, and communication technology, have enjoyed almost the same high rate of salaries and are placed in the top four in the 1997 survey. The salary growth in each engineering speciality, however, has directly resulted from the growth in the market shares and the total sale of the products developed by those particular specialities. For instance, the Digital Signal Processing (DSP) markets have been booming for the last few years. The entry of audio and video signals into the digital world mandates DSP and consequently has resulted in the continuing growth of DSP. Figure 2 shows the current DSP chip market.

Figure 4.2. Function-Specific DSP chip markets.



Source: Electronics Market Research

Investment in research and training. It is customary that governments and industries forecast the needs of society and marketplace and invest for research on those needs and for training the required workforce. Therefore, one indicator that engineers should investigate for possible job opportunity is in what area government and private sectors invest for research, development, and training. For instance the National Science Foundation (NSF) has been investing extensively in research on several areas such as optics, laser, electromagnetic and radiation (NSF, 1996). Several universities are founded by NSF to offer summer workshops for engineering faculty to enhance their knowledge to prepare students for a demanding career in technology and manufacturing. In recent years, Purdue University has received an NSF grant to run summer workshops in Rapid Prototyping, CAD/CAM, Automatic Data Capture Technology, and Programmable Logic Controls. The Universities of Virginia and Southern Methodist University also have been awarded funds to run summer workshops for engineering faculty in economy of design and design processes.

Tufts University and a team of northeast defense/VLSI companies has come together to train defense industry engineers in an emerging dual-use technology. One of the important and fast growing dual-use technologies is Mixed Signal ICs, where the U.S. holds the world lead. Technology Outreach Program (TOP) at the University of California, Irvine which is supported by federal, state, and corporate funds, offers free programs for qualifying unemployed engineers. The current TOP program focuses on microelectronics, biomedical electronics, digital electronics, MEMs and Sensors.

Summary. To stay employed or to be reemployed engineers must continuously upgrade their knowledge and skills. To do so, engineers should be aware of several issues. First they have to search and find out what knowledge and skills are in demand. They could look at the government and industries investments in research, development, and training programs. They should be aware of changes in the marketplaces and find out which companies gain more profit and which products are in demand in the global market. Second, they have to keep track of changes in engineering schools to figure out what areas are getting the attention of academia. Course offerings by engineering schools or technical institutions are a good indicator to see which technologies are popular in the job markets. Third, engineers must equip themselves with other nontechnical knowledge and skills. They should learn communication skills, team work, and sensitivity to environmental issues.

Chapter Five

CHARACTERISTICS OF A RETRAINING PROGRAM

Training or retraining programs are educational processes that substantially differ from formal schooling. The difference lies in goals, duration, setting, participants, and delivery systems. These peculiarities, then, warrant differential treatment and procedure. Although "training" and "retraining" are technically different, the idea of including "retraining" in a more general category of "training" program by Tracey (1984), helps to avoid confusion. Therefore, in this context and throughout this study, the general term of "training" is used to refer to both training and retraining unless it needs to be specified. The training programs themselves also are not homogeneous and, contrary to what is customary now, should not be treated similarly. That is to say, training programs must be tailor-made to fit their intended audiences and objectives, and an all encompassing universal model should be avoided.

The goal of training programs is to familiarize the workforce with the latest in knowledge and skills, and thereby keep them, as well as their employers, competitive in the marketplace. However, one should never lose sight of the fact that the participants in these programs are different people with different backgrounds, attitudes, and learning styles. Consequently, developing an appropriate delivery system is of utmost importance and a crucial factor for a successful outcome.

Training of individuals, whether currently employed or unemployed, will afford them the opportunity of being equipped for a productive and fulfilling career. These

programs also promote acquisition of leading-edge technology and consequent economic growth. Thus, both employers and employees could benefit from continuous training and retraining programs, especially at this time of ever present intense competition in the global marketplace resulting from drastic changes in social, economic, and political conditions around the globe.

Employers and employees will get a better return on their investments--time, energy, resources--devoted to a retraining program if the developers or providers know, in advance, exactly what all interested parties needed, wanted, and expected from the program.

Various models or guidelines have been developed for quality training programs. Each one of these models may be suited for specific training requirements. Obviously, however, none is universally applicable to all situations and individuals. A probe of some of these models and guidelines may help to synthesize these approaches and construct an alternative guideline particularly geared to retraining of engineers.

Hastings' Strategic Quality Training Model. One of the most accepted models in training programs is Hastings' (1995) Strategic Quality Training model. According to Workforce Journal:

> "The Technical Steering Committee for the Employment Service Revitalization Capacity Building Project has concluded that effective capacity building in the current business climate requires the adoption of a comprehensive training strategy. After reviewing the training strategies currently being utilized in all State Employment Service Agencies, the Committee recommends the utilization of Hasting's Strategic Quality Training Model." (Fall 1995, p. 3)

Hasting's model contains six steps, namely: determine customer needs, define

skills, measure skills, design and deliver training and evaluation, evaluate training, and begin again (Figure 1).

Obviously this model has some merits, since it has attracted attention of such an influential committee. Hastings discusses how an agency can provide a "superior service by capitalizing on current trends in business and technology." A superior service, in her view, is to "provide instructional content that teaches the skills and knowledge employees need to do a job, [and] promote employees' motivation to use the skills and knowledge learned in a training context ..." (p.2).

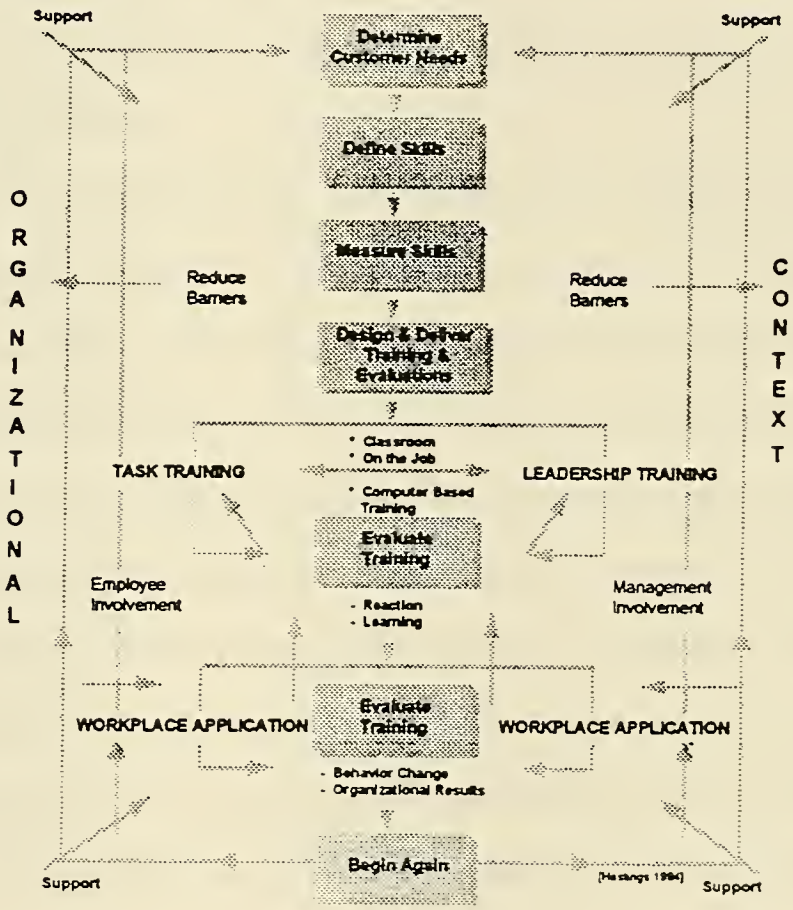
Some fundamental issues, however, may arise here. First, Hastings does not explain what type of instructional method is suitable for a training program. Providing a suitable and valuable instructional content for a particular training program is not as important as its delivery system. In fact, instructional design, which consists of course development and its delivery system, plays a crucial role in the learning process.

The participants in the training programs are adults, and adults' learning is different from younger learners. Despite the existing variations in the perception and background of adult learners, instructional methods for adult education should not be similar to those of traditional students.

Second, Hastings recommends designing a training program that motivates participants to apply their learned skills and knowledge in their workplace. This, however, remains as a statement only, and she does not specify how exactly this proposition will become real. An effective training program is one that not only motivates participants to learn the new skills and knowledge, but also teaches them how to properly

apply them. Consequently, an essential issue that should be addressed by a training program is how participants will learn the concepts and applications.

Figure 1. Hasting's Strategic Quality Training Model



The third potential shortcoming of Hastings' model lies in her emphasis on employers' needs and expectations. She writes about "customer's" and not "customers'" needs in "Step One" of her model and the "customer" is, in fact, the employer not the employees. She focuses only on non-educational requests and questions, when she mentions the participants' expectation. Failing to consider the needs and expectations of both parties in an educational setting, such as a training program, will result in an unsatisfactory outcome.

Hastings' model, most likely, was developed to train a specific group of people, namely blue collar technical workers. As such, it does not address the differences between blue collar technical workers and other trainees in term of personalities, needs, expectations, learning styles, and backgrounds. Hastings in her model mentions "creation of learning systems," "generative learning," and "improvement in participants' learning," which indicate her concern about the learning outcome of participants. Nevertheless, she does not indicate how these concerns may be addressed. In step four of her model, Hastings alludes to "training methodology that maximizes the opportunity for learning." Her emphasis, however, is on what material should be taught, and not on how to teach or how to develop a delivery system that could maximize "the opportunity for learning."

The effectiveness of the training programs highly depends on the quality and quantity of knowledge and skill gained by participants. It also depends on the resultant efficiency and productivity of participants at their places of employment. On the other hand, the effectiveness of a delivery system of training programs greatly depends on who the participants are and how well they learn. The intent of the Hastings model is to

present a guideline to training agencies--most likely state agencies--which they can customize to fit to their own training program. Training agencies, however, need to figure out the specifics of their own program, such as training strategy, and respond to particular needs of their workforce.

Principles of Training. Training is an educational process that provides an opportunity to employees, from newly hired to the upper level management, to become more effective workers in their enterprises. Tracey (1984) divides the formal training programs into four types with distinctive purposes. These are: entry-level or threshold training, remedial training, upgrading or advanced training, and retraining programs. These four types of training programs are designed: to train newly hired personnel to learn the initial job performance; to correct observed deficiencies in employees knowledge, skills, and attitudes; to improve and update employees' job skills and knowledge; and to equip employees with new skills, knowledge and technologies respectively. Tracey's approach to training programs is more realistic than others. As discussed earlier, a training programs deals with people's needs. On the other hand, it is obvious that people do not have a uniform and homogeneous attitude towards learning. People, even within the same ethnic group, gender, nationality, and class, live, think, and act differently. No one universal model could possibly be appropriate for all human activities. The training programs are no exception. Obviously, a variety of training programs are needed to fit the needs of different professions. Even training programs aimed at a given profession, depending on the particulars of each situation, should differ from one another. For instance, the newly hired employees need to learn the way the corporations function, and

adapt to the new working conditions and learn how to be an efficient and productive workforce. Those employees who already work for a corporation, on the other hand, just need to be retrained to upgrade their skills and knowledge. Consequently, these two groups of trainees require substantially different training programs.

Tracey believes "training programs function through personnel, material, and activities." He points to elements of training programs such as objectives, learning materials, and evaluation devices. An efficient and effective training program, according to Tracey, is one that "meets the needs of the organization and its employees." To respond to these needs, Tracey introduces the "Principles of Training" which is a guide to develop all types of training programs. Tracey describes his principles of training as follow:

1. Training requires the full commitment and support of top management, supervisory personnel, and the collective bargaining unit.
2. Training programs and activities must focus on problems that can be solved by training--remediation of deficiencies in knowledge, skills, and attitudes- and not on management problems--performance deficiencies attributable to inappropriate performance standards, inadequate supervision, employee lack of interest, laziness, or dissatisfaction with working condition, and like.
3. Training programs must meet both organization and employee needs, and they must encompass all type and levels of employees and cut across all divisions and units of the organization.
4. The pattern and arrangement of training opportunities must complement and implement the philosophy of the organization. Offerings must be balanced, well organized, and properly sequenced, provide adequately for differing needs and abilities, offer sufficient flexibility to managers and trainees, and be responsive to change.
5. Training programs must be developed through a systematic and orderly process. They must be built on a firm foundation of precisely defined job performance requirements. And the materials used must be structured to provide an integrated skills-building sequence of learning experience.
6. Training programs must employ delivery systems that are selected on the basis of training effectiveness, available technology, cost-effectiveness, and results.

7. Training programs must be validated to ensure effectiveness prior to full-scale implementation.
8. Training programs must include evaluation and feedback channels and mechanisms to permit refinement, updating, and continuing effectiveness.
9. Training programs must employ around principles of adult learning. They must involve trainees directly and completely in diagnosing needs and in planning, executing, and evaluating their own progress and accomplishment.
10. Training programs must provide ample opportunities to trainees to apply and practice newly required knowledge and skills (Chapter 1).

Tracey's model for developing training programs is highly distinguishable from other models in several issues that he refers to as "principles." First, it is hard to find any training program which points to the fact that participants are adults and therefore, the principles of adults learning should be employed in the training programs. As discussed in chapter two, adults learn differently than school age learners. They need to be actively involved in their own education and be able to evaluate their own progress and accomplishments. They are aware of their future careers and trends in businesses. Adults learners' goals, expectations, and needs are mostly clear. Therefore, they are mostly aware that why continuous training is needed. A serious training program must take these facts into account.

In the first, second, and third principles, Tracey explains the reason for a training program and the involvement of all levels of organization. Focusing on those problems that can be resolved through training is the second distinguishable characteristic of Tracey's principles of training. No training program has to be developed to solve management problems such "performance deficiency" or "employee lack of interest." Training programs have to be developed to facilitate employees to learn the job skill

required by the company, upgrade, update, or expand their current skills and knowledge. Training programs will help trainees to remedy the deficiencies in their skills and knowledge and thus stay employed. These trained employees, equipped with the latest skills and knowledge, in turn will help management to run the firm efficiently and productively, and accomplish their objectives. Consequently, employees and employers have a mutual interest in training programs and deep involvement of both parties will ensure an optimal outcome.

The fourth, fifth, sixth, ninth, and tenth principles focus on program design and system of delivery and they could be combined into one core principle. A good training program designer is one who: carefully collects and studies all related data and information; employs the latest training development methodology and technology; and designs a training program that shall meet needs and expectations of corporations at all levels. Such a program addresses all above mentioned principles.

The fourth and fifth principles of Tracey's model also designate systematic and orderly development of the training program and learning materials. Sequential development of the training program and learning materials is the only way that may satisfy both involved parties and respond positively to the learning ability of each individual. Sequential or modular program instruction will help participants to learn at their own pace. It will also allows those who already possess the knowledge contained in some modules to bypass those particular modules.

The seventh and eight principles pertain to evaluation and assessment. Here too, one could combine these two principles into one principle. The effectiveness of a training

program can be found by a holistic examination and evaluation. A comprehensive evaluation, according to Tracey, is one that consists of "what is to be evaluated, who should do the evaluating." Tracey believes in multi-channel feedback and evaluations. Regarding "what is to be evaluated," he refers to several elements and writes:" A learning situation involves trainees, instructors, course content, sequence, time allocations, instructional strategies, materials, equipment, and facilities." Consequently, an optimally effective training program depends highly on evaluation of all these factors.

Regarding "who should do evaluating," Tracey focuses on the perspectives of all involved parties. He criticizes the traditional training programs' evaluation that has considered only the training manager's perspectives. In fact, the trainees', the instructor's, the training evaluator's, the training manager's, and the line supervisor's perspectives all are necessary for improving a training program.

Guide for Designing Training Programs. In 1980 the Los Angeles Unified School District office of instruction published a guide for designing training programs. They believe a program developer not only needs to know "what should be done" but also needs to "suggest the sequence" that has to be followed. To this end, they developed a ten-step guideline for designing training programs that staff members have to take under consideration. These ten steps (The Reflector, December 1980) are:

1. Assess needs.
2. Set training goals.
3. Assess staff resources and skills.
4. Select training strategies and place them in the order they will occur in the program (prioritize).
5. State the objectives for each module of the program.
6. Predict the time schedule for each element of the modules.

7. Allocate a staff member who will be responsible for each element.
8. Assess the logistical elements.
9. Define primary client concerns.
10. Provide for evaluation.

The main idea of the "Guide for Designing Training Programs" is similar to other existing guides except in a few items as follow. Unlike other guides for designing a training program, the first step takes the humanistic side of participants and points to "participants' jobs, back-home environment, age, sex, race, and religion." Nevertheless, it places no emphasis at all on who the participants are and how they learn. As indicated earlier, these are the fundamental issues in developing a successful training program. The training developers must address them clearly before such a program could be devised.

An advantage of this guideline, however, is that it divides the program into multiple modules. This is because participants in a retraining program are not homogeneous in knowledge and skill. Thus, a uniform program for all learners, as exists in formal education, will result in less than optimum outcomes. The concept of modulization in this guideline, nevertheless, is limited to the strategies and does not apply to the instructional designs and methods of delivery. Consequently, the inadequacy of this guideline lies in its approach to understanding participants and failure in developing a suitable course of instruction for various constituents. Effective program developers need more than just a guideline. They look for a flexible and comprehensive working model with fast re-engineering potential.

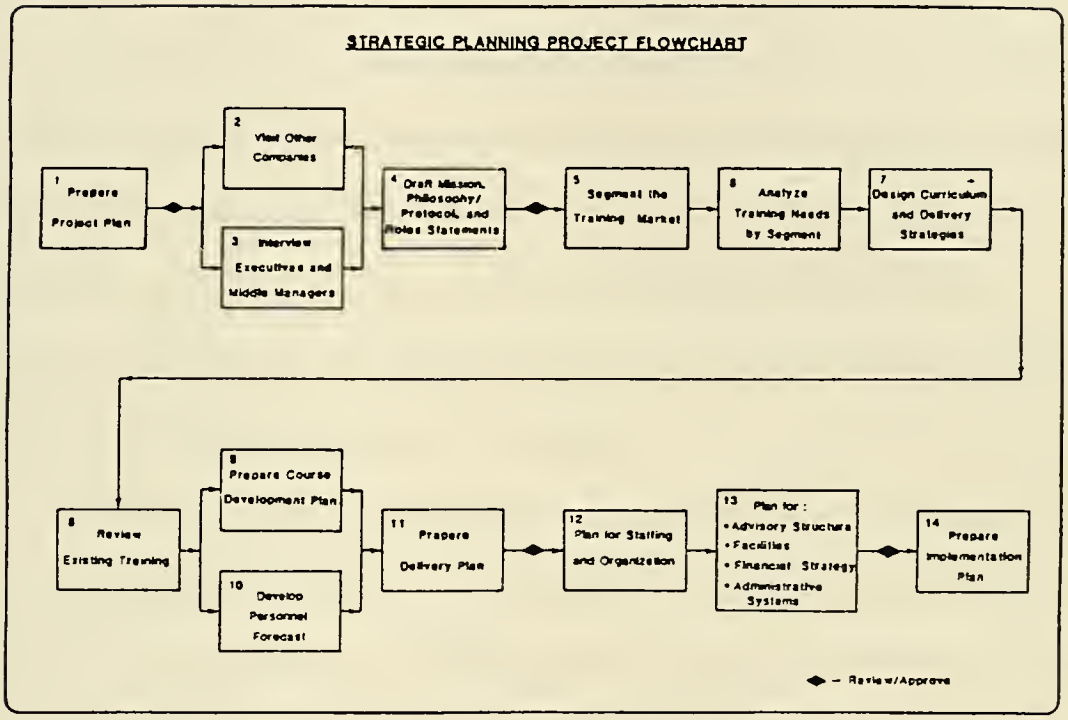
Basically, this guide presents the fundamental steps of designing a training program. Steps in this guide could easily be reduced if tasks are combined. For instance,

steps four, five, and six refer to modular training programs, and can be combined into one step. Step eight, "assess the logistical elements" and step ten, "provide for evaluation" are elements that make "the Guide for Designing Training Programs" distinguishable from others. Step eight provides a list of non-educational issues. Neglecting these factors and not planning for them will endanger smooth operation and efficiency of the training program. The logistical elements noted by this guide are: space, materials, housekeeping, administration, and recreation. Step ten also provides a complete list of elements of evaluation and assessment. Daily rating of satisfaction or learning, division of labor among staff, and report to the primary client are among major elements of a comprehensive evaluation process. The third and seventh steps refer to assessing the resources and can be reduced to one step. This combining will create a more practical and clear guide for designing training programs.

Svenson's Strategic Planning for Training. The former Dean of Planning, Methods, and Results for Bell System and Engineering Manager for AT&T, Ray Svenson, is a consultant for engineering departments of Fortune 500 companies. He developed a Strategic Planning for Training that includes fourteen steps with four "Review/Approve" segments right after steps one, four, eleven, and thirteen (Figure 2).

Svenson believes preparation for planning a training program starts with Strategic Planning because "a strategic plan relates what training has to do with what business has to do. Where is the business going, what are its major challenges, and what is the role of training in addressing these challenges?" (Svenson, 1986, p.45).

Figure 2. Svenson's Strategic Planning for Training.


STRATEGIC PLANNING PROJECT FLOWCHART
1 Prepare Project Plan
2 Visit Other Companies
3 Interview Executives and Middle Managers
4 Draft Mission, Philosophy/ Protocol, and Roles Statements
5 Segment the Training Market
6 Analyze Training Needs by Segment
7 Design Curriculum and Delivery Strategies
8 Review Existing Training
9 Prepare Course Development Plan
10 Develop Personnel Forecast
11 Prepare Delivery Plan
12 Plan for Staffing and Organization
13 Plan for:
• Advisory Structure
• Facilities
• Financial Strategy
• Administrative Systems
14 Prepare Implementation Plan
◆ = Review/Approve

What Svenson's model tries to do is establish a basic direction to training program developers. Svenson's model--in many respects--is similar to other models of designing training programs. Consequently, to avoid repeating previous discussions, in the following passages only Svenson's approach to curriculum and course development, delivery system, and evaluation will be reviewed.

Svenson believes in a five-year plan for many issues, including curriculum development and delivery systems. In the five-year plan for curriculum development, he suggests that the training program developers need to answer to the following questions:

"what the curriculum need to support the business? Who are the target audiences? What sorts of courses are needed? What are the resource requirements to meet the needs?" (p.46).

Although Svenson is concerned about who the target audiences are, he does not explain why knowing the audience is important. Obviously, the curriculum varies from one type of audience to another because people learn differently and their learning capabilities highly depend on their characteristics and backgrounds. But in fact, Svenson's concern with "who the target audiences are "remains a statement and fails to develop and consider the human side of training.

He views learning as a predetermined and inflexible process. Training, however, is an educational process and deals with teaching and learning. Learning, on the other hand, is an internal process and depends mostly on people's characteristics and attitudes. As noted by Miller, "As trainers, we sooner or later come to the realization that one of the most critical factors in training practice is the fact that learning is an internal process" (Miller, 1983, p.113). It is important to recognize and appreciate the differences in learning capabilities and learning styles of participants, in construction of any educational program including retraining.

Svenson's five-year plan for delivery gives some details and helpful suggestions. He suggests that having a strategic plan for delivery is important and indicates that once "we know what we need, how are we going to provide it? Are we going to use group-paced, instructor-driven training exclusively or are we going to mix that up with self-paced or computer-based training?" (p.46).

As discussed in chapter two, the most suitable delivery system for retraining engineers is a combination of instructor-driven, self-paced course materials, and experimental (computer-based) training. Obviously all these options depend on what resources are available.

To find out if the proposed training program will meet the company's needs and expectations, Svenson suggests establishment of a system that measures the results. The proposed training program also needs a system of collecting and presenting the measured data and information. The measured data and information will help the training program developers to assess the training activities; to determine whether the training program is meeting the business goals of the organization; to find out if the training program's needs are being met; to decide if any other course needs to be added to complete the curriculum.

Guide for Designing a Retraining Program for Engineers. Many professional trainers like Svenson are good organizers and have excellent ability to plan and carry out a training program especially at the workplace. But the problem is, they look at the training program mostly from employers' point of view and since many of them possess managerial skills, their model or guideline primarily lacks a meaningful connection with education and its process. On the other hand, educators and experts in the field of education may fail to adequately take into account the employers' needs and expectations. The best solution, apparently then, is to establish a continuous linkage between these two groups, a linkage that enables trainers to successfully integrate the corporate strategies, the future of the marketplace, and the participants' needs and expectations.

Understanding the participants' characteristics and learning styles will lead the

providers to design an effective course of instruction. Clearly, however, this represents only one side of a multi- sided issue such as a retraining program. To develop a comprehensive retraining program for engineers, it is essential to thoroughly examine and address all sides. The following guide of six-step instruction for designing a retraining program, inspired by "Hastings' Strategic Quality Training,""Tracey's Principles of Training," "Guide for Designing Training Programs," and "Svenson's Strategic Planning for Training," may present a more comprehensive guideline for developing a retraining program. These steps are:

1. Determine participants' characteristics, learning styles, and expectations.
2. Determine employers' business strategies, goals, future needs and expectations, as well as those of their Competitors.
3. Identify the future needed skills for employees (i.e., technical, managerial, or both) and related skills among staff (especially for in-house retraining programs).
4. Select retraining strategies (i.e., draft a mission, state the objectives, duration of the program, forecast cost and annual budget, select instructors, set rules and regulation, identify the available facilities and resources).
5. Design and develop an appropriate curriculum and delivery system.
6. Select evaluators (managers, human resource offices, placement agencies, instructors, and participants). Design evaluation and assessment policy and instruments along with feedback systems for continuous improvement.

A more detailed presentation of this model and its steps follows for the purpose of added clarity.

Step one. As was noted in chapter one, engineers are individuals who prefer to build or develop something rather than discuss it. They like to focus on concrete, tangible, real, and practical problems. The majority of engineers tend to be decisive, determined, and constructivistic people who would rather have a system and a plan. They are result-oriented people who savor arriving at a conclusion in a logical and analytical manner.

The engineers' mode of learning was discussed in chapter two. The findings of that discussion indicate that a successful engineering retraining program must incorporate an experimental, practical, concrete, logical, visual, and sequential (modular) presentation. Program developers must create an active learning atmosphere with suitable learning methods and standards of performance. Engineers predominately embrace having mentors, plans, and guidelines, and dread having many rules and regulations. A successful program developer must not neglect to probe these issues thoroughly and properly and take them into consideration.

Since engineers are sequential and concrete types of individuals, they learn better when the retraining course materials are divided into units. They tend to focus on one concrete and specific assignment and, based on a just learned unit, find adequate solution. In other words, the Personalized System of Instruction (PSI) method may be the best choice for program developers. But to train engineers for an ever expanding global economy, more diverse workplace, and adoption of teamwork in most American corporations, the concept of cooperative learning should be integrated into the learning

process.

To stay competitive in the global market the American corporations need innovator and creative engineers. To possess these qualities, engineers need to apply both deductive and inductive reasoning in their work, but as was mentioned in chapter two, deductive reasoning is the dominant mode of reasoning among engineers. Consequently, retraining program developers need to adopt scientific reasoning, which combines both types of reasoning, in their programs.

Engineers participate in a continuing education program, such as retraining, for many different reasons. Therefore, before designing or developing a retraining program, it is essential to find out the reasons for engineers' participation. According to a study of Professional Engineers in Industry (1996), engineers attend a continuing education program for the following reasons:

1. Broaden their technological background.
2. Desire to advance their knowledge in a specialty field.
3. To receive a raise or promotion.
4. To keep up-to-date with advancing technologies.
5. Required by company.
6. Required by change in assignment.
7. Do better job for clients.
8. Doing a better job of management.
9. To receive an advanced degree.
10. To obtain better position with another employer.
11. To stay employment during a layoff crisis. (p.25).

Mertens (1978) conducted a study on responses of 179 professionals--mostly engineers--enrolled in a television-presented course in economic analysis for engineers at the University of Kentucky. He listed nineteen different factors that motivated participants to attend this particular course. The top two factors belonged to professional

advancement such as "to learn new ideas that might enhance my job performance" and "to acquire specific knowledge of a field or subject." The lowest factor related to external expectation or influences such as "I want the certificate that is awarded at the end of the course" and "my agency/supervisor strongly recommended that I attend."

Morris (1978) conducted a study on the continuing engineering education and job-performance patterns in the San Francisco Bay Area. The results of this National Science Foundation supported study was based on responses of 396 engineers from four organizations, Ford Aerospace and Communications, NASA-Ames Laboratory, GTE-Sylvania, and FMC Machinery. The following are adopted from item seven in the results of Morris' study:

1. Non-credit technical CE is measurably effective in leading to increased compensation.
2. For the sample group studied, non-credit technical CE was significantly more effective than credit technical CE.
3. Non-academic instructors are capable of doing an effective job of teaching.
4. Non-credit technical CE course offered away from the place of employment can successfully impact on performance (pp.176-185).

The Studies by PEI, Mertens, and Morris indicate that most engineers attend a continuing education program, not to pursue another degree, but to advance their knowledge and skills. Therefore, they prefer to take a non-credit course with someone who is expert in that particular area. These are very important factors in developing a successful retraining program and should be given top priorities in any program developer's agenda.

Another crucial factor in designing a retraining program is the role played by the

students in the learning process. Participants in retraining programs are all adults, and as was discussed in chapter two, adult learners are self-directed, would like to be involved in the program or course selection, and need to arrange their own learning process. Thus, they should be involved and their views should be considered in the planning and evaluation processes of a retraining program.

Step two. The engineering retraining programs must be designed to furnish industry with a quality workforce in order to enable the businesses to meet their strategies, goals, and expectations. At the dawn of the twenty-first century and at a time of drastic changes in economic, social, and political forces around the world, American firms need, and search for, new dynamic and flexible strategies that enable them to respond properly and quickly to the evolving conditions of the global marketplace. The new business strategies, in turn, demand new training and retraining programs. It is in response to this need that in 1985 a three-year national policy study was launched by Work in America Institute. The study, dubbed "Training for New Technology," examined organizations that adopted successful training strategies and recognized the following five major factors that affected industries and their desire for training. (Casner-Lotto & Associates, 1998, p.2).

1. Increased global and domestic competition.
2. Rapid changes in technology.
3. Widespread mergers, acquisitions, and divestitures.
4. A better-educated workforce.
5. Occupational obsolescence and the emergence of new occupations.

As indicated before, these are the major factors that concern most firms. Individual firms, however, have their particular needs and agenda. To obtain some insight as to what other factors may play a role in a company's desire for training and retraining,

it is worthwhile to look at the training programs at those corporations that traditionally have offered such a program for their employees.

At Motorola Incorporation, the Training and Education Center is responsible for providing the employees with "the skills needed to keep the company competitive" (Plous, Jr., 1989, p.52). Training criteria at Motorola is simple and clear: all training must be job-related and must support current corporate strategic goals. Strategic goals of Motorola are "product improvement and inventory productivity."

About 1000 of the Aerospace Electronic System Department (AESD) of General Electric Company's 3,500 employees in the late 1980s worked in the engineering division. With annual sales of about $400 million, ASED's total training budget exceed $1 million a year (Hickey, 1988). This figure shows how important training employees is for ASED. ASED has its own Continuing Engineering Education Program (CEEP) which has an advisory council. Half the members of this council are engineers and the other half are managers, and their task is to "report trends and changes in technologies relevant to ASED, identify emerging areas of potential business, and help to develop needed courses." (p.122).

Packaging beer for distribution and resale costs "approximately one-half of sales revenues" at Miller Brewing Company (Gutchess, 1989). For Miller Company this is the area where inefficiency is at a premium. To overcome this problem, Miller introduced a new technology for its packaging process and needed to train its employees to be able to run the new system. Miller hired an outside training vendor--Amatrol--to train its employees to become flexible enough to respond quickly and effectively to production

and packaging problems. Obviously, Miller's business strategy was to optimize the packaging, and consequently overall costs, in order to compete more effectively with its competitors.

Thomas J. Watson, the founder of IBM Corporation, believed there was no saturation point in education, and the profitability and growth of the corporation depended upon the knowledge and skills of its employees (Casner-Lotto, 1989). IBM's employees still benefit from Watson's legacy and training is an integral part of their employment. IBM's deep commitment to education of its employees leads them to innovate a cost-effective approach in training called "System Approach to Education."

Step three. As technologies change rapidly, the current skills of employees, including engineers who are at the center of these changes, become outdated and obsolete, and acquisition of new skills becomes imperative for them to remain productive and efficient employees. A retraining program developer must be aware of the types of skills and knowledge that are needed at a particular workplace (for an in-house program) or are demanded in the job market. To make the in-house retraining programs more job-related and cost effective, it is necessary to discover who possesses the needed skills and knowledge among staff.

Step four. Selecting retraining strategies is the most important part of designing a successful retraining program. Program developers must collect all relevant data and information in order to have a holistic and clear vision of the program. They must identify all possible available resources and all the internal or external supports that they can obtain. Program developers must have an explicit mission statement with a long-term

budget plan and a comprehensive set of rules and regulations for all parties involved. They must establish a forecasting, decision-making, evaluating, and supporting council, staffed by experts from economics, business, education, and technology disciplines. Obviously an in-house training program differs in many respects from the training programs offered by public or private educational institutions or cooperative programs of corporations and universities. Each of these types of training programs have their own specific missions and goals, and in most cases, one cannot replace the others. In-house training is convenient and cost effective for corporations. Therefore, companies prefer to have their own in-house training rather than hire an outside training vendor.

The advantages of an in-house training program over other types are:

1. Allows instructors to pace the course according to trainees' skill levels.
2. Has ability to diverge from the curriculum to deal with problems brought to class from the plant floor (direct job-relevant training).
3. Permits the essential hands-on equipment experience.
4. Is flexible in time and scheduling.
5. Is cost-effective (using corporations' resources: facilities and instructors from senior and experienced staff)
6. Renders an easy access to get feedback for continuous improvement and adjustment of the curriculum.

The shortcoming of an in-house training programs, especially those managment-made in-house training programs, stems from inadequate knowledge of managers about education and its processes. Educators and trainers who run the off-house training

programs have their own particular problems. In many cases, they are not being completely aware of business strategies, goals, and needs of employers. Active involvement of an organized supporting council, made up of members with diverse backgrounds, plays a crucial role in designing and implementing a successful training program.

Implementation of a training program may start with planning for facilities. Typically, expenses of running the facilities consume most of the training budgets. With a long-term program, the costs may be so prohibitive that they cause the whole training program to come to a halt. Consequently, program developers must have a well developed long-term plan and adequate financing for facilities.

Selecting the right instructors is another important issue in the training programs. An ideal instructor is one who possesses not only proper knowledge and skills but has the ability to adequately transfer his or her expertise to trainees. Instructors must be able to establish a meaningful connection between theory and experiment. They have to be industrial-experienced people and familiar with training techniques. Instructors must establish an active learning environment and give trainees an opportunity to become fully involved in their own training.

Right timing and duration of training programs are also among the important factors to motivate trainees. Both employers and employees, each for their own reasons, want to minimize the training time. While employers' concern relates to costs and quick return on their investments, employees are concerned with their commitment of time and possible out of pocket spending.

Step five. For companies that need to compete in today's intense global markets, the question is how to train their employees, not whether their employees need to be trained or retrained. Training is an educational process and therefore, similar to formal education, a training program needs to develop curriculum, course, delivery system (instructional method), and measuring performance tools. These are the most important elements in an effective training program. In fact, the "System Approach" which many training developers have adopted, is based on these elements.

For training employees, IBM Corporation has developed an educational process known as "System Approach to Education" (Casner-Lotto, 1988). "IBM's System Approach consists of four major steps: a detailed Curriculum design for every major job category, based upon defined business requirements; instructional design for each course; course development led by an interdisciplinary professional development team; and delivery of education through a variety of methods." (p.256).

Curriculum design in the training programs must be based on the corporation's business strategies, the needed skills, and employees' performance. To accomplish this task, the curriculum and course development must be carried out by a team of multidisciplanry professionals such as engineers, managers, supervisors, and educators.

The delivery system design in fact is more important than curriculum design. A proper instructional method is an essential element that helps trainers to meet the goals and needs of the training program. Consequently, the training developers should make certain that the course development and delivery respond adequately to trainees' needs and their learning backgrounds and abilities. The training developers should be flexible

when they want to design a delivery system. A flexible delivery system helps trainees successfully complete the retraining program and be ready to apply the gained skills and knowledge at the workplace. Standards of performance also have a significant impact in the training programs and it must be set for the learners to achieve the goals of training.

Experts in training development have developed several guidelines for developing training materials over the years. Among those, Tracey's guideline (1984) highlights many important aspects of developing training materials to training developers. His guideline consists of eight steps as follows:

1. Accuracy. The content of every lesson must be completely accurate to ensure that they are not distracting trainees' confidence in the training program.
2. Focus. Training developers should include in the training program only the information, problems, and activities actually needed to achieve the objects of the program. They should keep "nice-to-know" information to minimum. Instruction should be direct and simple along with example, illustration and summary.
3. Difficulty level. Instruction and instructional materials should be presented at the verbal and technical level of trainees. The amount of the new material should be limited to the complexity of material and trainees need to perform their jobs.
4. Learner involvement. Training developers must keep in mind that learners must be directly and completely involved in the learning process.
5. Tailored learning activities. Adults learn best when training activities are tailored to their individual needs, backgrounds, experiences, skills, abilities, knowledge, and learning styles. Learning activities must start where the learners are, not where the trainer thinks they ought to be. Individual differences must be identified and accommodated if learning efficiency and effectiveness are to be achieved.
6. Realism. Training programs, materials, and activities must be involved real, job-related problems and issues.
7. Structure. Learning tasks must be broken down into manageable units, sets, or steps.
8. Application. The focus of learning activities must be on direct, hands-on experience, doing rather than listening, reading, or observing. (pp.304-306)

The engineering retraining program developers must take some elements in Tracey's guideline under careful consideration. According to Tracey's guideline, training materials must be specific, job-related, and experimental; learning methods must vary with trainees' backgrounds and learning abilities to offset factors of fatigue and boredom; course materials should be divided in units and appropriate materials for sequential learning must be provided (cases, problems, discussions, and reading); and theories of adult learning must be integrated in to the delivery system. Obviously, the retraining program for engineers must consider other concern issues which relate to engineers' characteristics. As discussed in chapter two, most engineers benefit from explicit instructions, starting with their practical experiences and sequential presentation. An ideal training session may start with a mixed visual and verbal presentation of a specific topic follows by hands-on laboratory work. The training developers must employ scientific reasoning--combination of deductive and inductive reasoning--in the course content and instruction. Scientific reasoning helps to increase the engineers' creativity and consequently train them to be more innovative. Engineers will benefit substantially from an integration of a mentorship program especially in an "in-house" retraining program. Engineering subjects are direct applications of science and understanding of science is possible through concept learning, mathematics, and experiments. Consequently, the engineering retraining developers must develop courses based on concept learning, mathematical proof, and hands-on sections. They also must provide appropriate materials such as cases, problems, discussions, and reading for sequential learning.

Step six. The conclusive proof of adequacy and effectiveness of any system is possible through a holistic evaluation. To design an effective training program, training developers should strongly reject the traditional methods of evaluation. The traditional methods focus on the managers' view on outcomes of training program and trainees' respond to a distributed evaluation sheet at the end of the program.

To be certain that the training programs have met the goals of training, training developers should know what is to be evaluated and who should do the evaluating. All components of the training program--trainees, trainers, curriculum, course content, delivery, equipment, and facilities--need to be evaluated. A continuous evaluation at the different stages of the program by multiple evaluators may lead training developers to the desired outcome. Multiple evaluators must consist of all involved parties--trainees, trainers, supervisors, management, and placement agencies for unemployed trainees--in the training program (Figure 3).

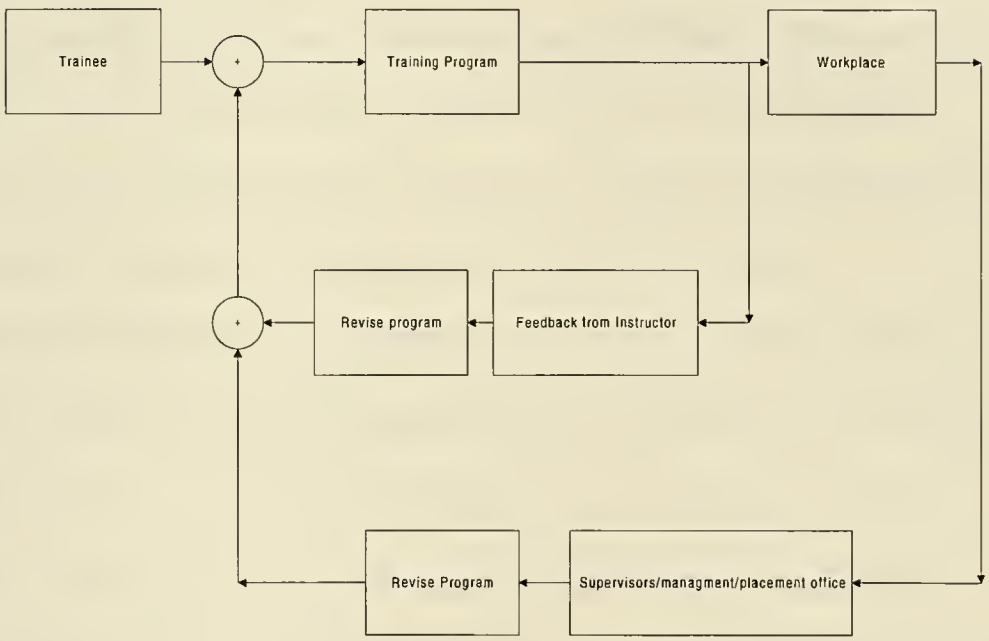
Analysis of participants' knowledge and skills before and after a program may provide the best possible tool to evaluate the effectiveness of the course content and the instructional method. Obviously, participants' satisfaction with the training program will optimize their gained knowledge and skills. Managers and supervisors' feedback will help training developers to find out the consequences of the training program on business strategies of the company. Casner-Lotto (1988) agrees with this idea and introduces four sources of data that have to be considered in the evaluation process.

These sources are:

1. Post-training surveys to determine reactions of trainees.

2. Knowledge and skill tests administered before and after training.
3. Interviews with trainees and observations on the job to determine the application of training in the workplace.
4. Impact on business results. (p.266).

Figure 3. A typical multiple evaluators flowchart.



Casner-Lotto also believes the managers have to be trained in "the same techniques as trainees so that they are able to judge whether or not the training is being practiced on the job." Hastings agrees with Casner-Lotto and states that "the Strategic Quality Training model offers corresponding training for training participants' supervisors (leadership training) as well." She argues that "task training is augmented with 'supervisory training' because many individual supervisors do not know how to support employees' transfer of training efforts" (1995, p.10). On the evaluation of a

training program, Hastings' offers almost the same procedure as Casner-Lotto does. Hastings' evaluation procedure intends to measure: "participants' reaction to the training session, participants' understanding and/or ability to use the new skills, participants' behavior change or long term application of training, and organizational results" (p.12).

As noted in previous steps, the training developers present different views on how to develop, design, and carry out a training program. On evaluation and assessment, however, most of them agree with one another. They prefer to collect data and information from all parties involved in the training program such as shown in Figure 3. They believe in evaluation of all components of the training program.

Evaluation of Existing Retraining Programs. In response to needs of engineers and industry, federal and state governments and private agencies have developed a variety of retraining programs. Each of these programs differs from others in objective, mission, goal, cost, and duration. Traditionally, federal and state governments offer most of their training programs through state universities and colleges. Those states which have higher rate of unemployment or their local industries are going through fundamental changes, provide more training programs than others. Private and state universities and colleges offer variety of programs as their regular activities. Their programs vary from in-campus programs--certificate, degree, and short courses--to in-house training programs. Professional societies offer courses that are within their domain of activities and are demanded by their members or companies. Satellite institutes offer distance

learning programs for diverse professions throughout the nation. Training institutes offer only training and professional competency programs for some specific professions.

Table 1. displays the variety of programs which these institution offer for engineers and associates.

Providers / Programs	Government Agencies	Universities/ Colleges	Professional Societies	Training Institute	Electronic Universities
Assistance to industry	X	-	-	-	_
On-site	X	X	X	-	
Fixed	-	X	X	-	X
Self-paced	-	X	-	X	X
Short course/ Certificate	-	X	X	X	X
Degree	-	X	-	X	X
Distance learning	-	X	X	X	X

Participants in these programs have almost no knowledge about outcomes of these programs, because there are not many studies available on the effectiveness of these programs. Often, participants have no choice but to rely on whatever providers claim. Therefore, to present a comprehensive study on retraining programs for engineers, it is necessary to evaluate at least one program from each category.

The following are evaluations of training or retraining programs at Government Agencies (in the States of Georgia, North Carolina, and California), Institutes of Higher Education (Northeastern University), Professional Societies (International Society for Measurement and Control), Training Institutes (International Association for Continuing Education and Training, IACET), and Electronic Universities (National Technological University, NTU).

Government Agencies (in the states of Georgia, North Carolina, and California). Traditionally, the federal and state governments provide technical assistance programs to manufacturers and training programs mostly for blue collar workers. Their retraining programs for professionals are usually seasonal and depend on the rate of unemployment among them. The state universities and colleges are the main resource for governments' assistance and retraining programs.

The governments' university-based programs provide assistance at no cost to manufacturers for productivity and management improvements. These programs also help manufacturers for technological modernization and staff training for new technology. The Georgia Institute of Technology administers the largest program of this type, with a network of twelve regional offices and twenty-six staff members.

The North Carolina State University (NCSU, Online) is active in interdisciplinary training, and continuing education mainly for adults. The office of Continuing and Professional Education (CPE) at NCSU developed several programs according to the educational needs of the businesses, industries, government agencies, and professional groups. Each year, the office of CPE provides 500 to 600 short courses for 20,000 adult

participants. In addition, NCSU established the Training Research for Automated Instruction (TRAIN) project with a grant from Air Force Office of Scientific Research (AFOSR). The objective of TRAIN is to codify pedagogical principles for automated instruction. The Industrial Extension Service (IES) is another nontraditional program at NCSU. The objective of this program is to provide engineering and industrial management assistance and education to help North Carolina industries gain a competitive advantage. For the fiscal year 1995-1996, IES provided technical service, applied research, and continuing education to more than 41,000 firms and individuals.

The state of California provides a variety of programs for industry and technical people. El Camino College in Los Angeles is chartered: to help the small and medium-sized manufacturers with technology transformation; to keep aerospace suppliers competitive; and to assist companies in making transitions from defense to commercial applications. The California State University at Long Beach offers a training program for engineers only. Its Engineering Problem Solving Initiative and the Continuing Education Program provide seminars for engineers working in local government and industry.

The Technology Outreach Program (TOP, Online) is one of the most practical and effective government' training programs for unemployed engineers. TOP is a program at the University of California at Irvine and is supported by federal, state, and corporate funds. TOP's mission is to support industry and entrepreneurs with resources of the School of Engineering. This support includes: product prototyping, industry education, engineering services, and retraining. All fees are paid for qualifying unemployed engineers.

The advantages of the government programs are:

1. They are cost effective (no cost usually).
2. They are not commercialized (they are not money-driven programs).
3. They are specific in both content and time.

The disadvantages of the government programs are:

1. They are seasonal and have no continuation and published assessments.
2. They are for local people.
3. They mostly depend on the full-time faculty.
4. All of them have almost similar instructional methods regardless of participants' backgrounds and learning styles.

Institutes of Higher Education (Northeastern University, Online). Northeastern University offers three different programs as follow to help individual and industry to grow.

1. Northeastern University established continuing education programs more than thirty years ago to provide a practical, high quality career-related education. At the Center for Continuing Education (CEC) courses are taught primarily by practitioners in their respective fields. Program development, courses, and seminars are based on market needs and wants and are offered at off-campus locations and at company sites. Courses are also transmitted via microwave and satellite from main campus to other locations.

2. Through its Corporate Training Group, Northeastern University offers non-credit and credit courses in a variety of subject areas to help businesses to grow. More than 50 certificate programs are offered in diverse subject areas and Northeastern can

customize a training program to fit the company's unique requirements.

3. The State-of-the-Art Program (1997) offers evening, day, and Saturday courses, seminars, and on-site training designed for working professionals seeking practical, hands-on education in a work-related area of technology. The State-of-the-Art Program is the largest program of its kind, delivering training in the demanding areas of networking and communications, software engineering, and microelectronics/computer technology. According to the Northeastern Catalog, the advantages of their programs are:

1. Industry professionals as faculty.
2. Flexible scheduling and formats.
3. Multi-Media delivery.
4. Cost effective training.
5. Results-oriented.

On the first, second, and third advantages, Northeastern may has some supportive arguments for its claims, but it may not be able to present similar arguments on fourth and fifth advantages. The following statements and interviews may clarify this discussion.

Based on its State-of-the-Art catalog, only one out of 133 instructors who were teaching in the spring term was a full-time faculty member. Fourteen of them had a Ph.D. degree while forty-six instructors had only B.S. degree and nine of them had no terminal degree. Most of them were either working for industry or were consultants. The continuing education courses meet for one two-hour session per week for a total of ten weeks (a twenty-hour course). Tuition varies between $685 and $1,195 per course which is much higher than IEEE's tuition. For instance, tuition for a Visual Basic Programing course at Northeastern is more than 40% higher than IEEE Program.

The following are the highlights of interviews with Dean of Continuing Education

and Director of Engineering and Information Technology Program at Northeastern University.

The highlights of an interview with Dean of Continuing Education (conducted in March 15,1997).

1. Go to organization, look for their needs, find out what they are looking for, come up with a program, and give them a discount for in-house training.
2. The State-of-the-Art program is different from a degree program. There are no background or degree requirements and no prerequisites.
3. Something between 80 and 90 percent of the State-of-the-Art program students have an undergraduate degree.
4. Traditional faculty at University have not much industrial expertise.
5. Evaluations are based on students' evaluation, classes visit by administrators, and opinion from industry.
6. Courses are developed based on students' or industry's needs.
7. A satellite program is very expensive and does not provide interactive education.
8. Individualization of education does not work.

The highlights of an interview with Director of Engineering and Information Technology Program (conducted in April 1997).

1. The State-of-the-Art program was started thirty years ago and has changed through years in response to the students' needs.
2. Each course is limited to a maximum of twenty-five students.

3. Five out of the 180 faculties at the State-of-the-Art program are full-time faculty member, the rest are practitioners.
4. There is no rigid standard for hiring faculty. They should really know the topic. Degree is not an issue.
5. Interaction between students and faculty outside class is depended on an individual faculty
6. Most company like to meet instructors before signing a contract for the retraining program.
7. Students determine what they need and our programs are more "buffet-table" (self-paced) type than fixed type.
8. Evaluations are based on students' evaluation at end and middle of term, classes visit by administrators (only for new faculty and new topic), no opinion from company (may be for Corporate Education).

The Center for Continuing Education at Northeastern, however, may respond to students' and industry's needs; may offer self-paced training programs; may hire only expert instructors; may offer a flexible and interactive schedule and classroom. Nevertheless, their programs are not cost effective and based on their evaluation policy, they may not be able to claim their programs are results-oriented.

Professional Societies (The International Society for Measurement and Control-ISA Training Institute, Online). ISA is a nonprofit engineering society with nearly 50,000 members around the world and is in Raleigh, North Carolina. Its programs are designed especially for professionals requiring expert training in measurement and control. All ISA

training courses are offered at the ISA Training Institute in Raleigh, North Carolina and its customized and private training programs can be delivered to companies' sites. ISA also offers the certificate of completion for its "Online mini-courses." Tuition for a two-day training course--1.6 Continuing Education Unit (CEU)-- is $735 for members and $795 for nonmembers. Tuition for a three-day--2.4 CEU--is $935 for members and $995 for nonmembers. For ISA member engineers the completion of the "Engineering Skills Training Path" costs close to $23,000 and it costs more than $24,000 for nonmembers.

The ISA Training Programs consist of the following three paths and each path targets a specific skill.

1. The "Fundamental Skills Training Path" offers four basic and principle courses for newcomers to the field of instrumentation and control, technical sales representatives, and managers.
2. The "Technical Skills Training Path" offers thirteen core courses and three specialized courses designed for those who troubleshoot, maintain, install, calibrate, and tune devices and systems.
3. The "Engineering Skills Training Path" offers eighteen core courses and ten specialized technology courses. These courses are designed to provide in-depth coverage of measurement and control variable, systems and design engineering.

Because each course of these three paths has assigned prerequisites, participants will waste little time on introduction and focus directly on what they want to learn. Experienced industry professionals teach these hands-on training courses. These expert

instructors, instead of taking participants through the text, illustrate important theories and techniques and show participants how to apply them to their workplace.

The advantages of ISA training programs are:

1. ISA offers fixed and customized training programs in its campus, at workplaces, and online.
2. Participants can complete their training program at their own rate.
3. Instructors are experienced industrial professionals.
4. ISA offers practical, hand-on, specific, and job-related courses.
5. The instructional method consists of visual demonstrations and verbal lecturing of theories and applications.

The disadvantages of ISA training programs are:

1. Most engineers, especially unemployed engineers, are not able to afford the cost of ISA training programs.
2. The evaluation mechanism of ISA is unknown (if there is any).

Training Institutes (International Association for Continuing Education and Training, IACET, Online). IACET--formerly the Council on the Continuing Education Unit--is a non-profit association of education and training organizations. IACET is devoted to constructive and consistent use of the Continuing Education Unit (CEU) and to the improvement of the quality and effectiveness of continuing education, training and human resource development. CEU is a nationally recognized standard in the evaluation and development of continuing education and training. One CEU is awarded for every ten hours of instruction (sixty-minute hours). The goals of IACET are:

1. To promote IACET standards world-wide.
2. To promote and conduct research on effective practices in continuing education and training.
3. To publish, disseminate, and promote the use of research-based standards for enhancing continuing education and training.
4. To develop and disseminate educational programs and materials for the continuous improvement of the continuing education and training.

Any organization or institution involved with continuing education and training is encouraged by IACET to become: CEU Sponsor, Certificate Provider, or Associate Member. More than forty institutions, including government agencies, the Armed Forces, colleges and universities, professional and trade associations, hospitals, and labor organizations are, members of IACET.

The Institute of Electrical and Electronics Engineers (IEEE), Incorporation, is an authorized CEU Sponsor Member of the IACET. IEEE's Educational Activities Board (EAB) sponsors its continuing education program that includes short courses, workshops, home-study and in-house presentations in cooperation with colleges and industry. The continuing education committee of the EAB develops and recommends educational programs that have two major goals, first, "to alert the members to the need to stay on top of changes affecting technology and engineering environment," and second "to provide the means to sharpen old skills and add those needed skills for career enhancement" (IEEE, 1996, Online).

IEEE offers one-day or multiple-day courses for members and nonmembers through its continuing education program. Participants, especially members, enjoy the low registration fee for the same quality course which is offered by other institutions

including universities and colleges. The members' registration fee varies from $150 to $300 for one-day and multiple-day courses respectively. Instructors are either experienced industrial professionals or they are well recognized full-time faculty.

Engineers in the fields of electrical or electronics cannot find any better program than IEEE's program for upgrading and updating their knowledge and skills. Nevertheless, the problem is that engineers cannot plan for course taking, because course offerings are announced at most two or three months in advance. The other disadvantage of this program is that most of its courses are offered only once, which leaves no reason for evaluation.

Electronic Universities (National Technological University). The National Technological University (NTU, Online) is a media-based or an "Electronic University" which was established in 1984 and is located in Fort Collins, Colorado. The central purpose of NTU is to supply appropriate human resources to meet the technological and economic challenges of the future. Therefore, the NTU programs focus exclusively upon engineering disciplines and other fields deemed to be important to the development and maintenance of appropriate technology. The range and variety of academic offerings and experiences reflect the rapidly changing needs of technological society, the aspirations of the students, the expertise of participating faculty, the curricular requirements of the selected programs of study, and the results of research and development.

To achieve its mission, NTU offers degree (Master) and certificate programs through its forty-six participating universities to engineers and computer science professionals at their workplaces across the United States by satellite. In Massachusetts,

the University of Massachusetts at Amherst, Boston University, and Northeastern University are among the NTU participating universities. The Certificate of Completion Program is designed for those who already have Master or Doctoral degrees and do not wish to pursue another advanced degree. It provides recognition of academic accomplishment while upgrading technical competence or reorienting professional careers.

The university depends upon faculty drawn from participating institutions to engage in and prepare students for scholarly endeavors, creative activities, and basic and applied research. Only the Advanced Technology and Management Program of NTU draws instruction from university faculty as well as from consultants and industry experts. At NTU, students are responsible for their own individual growth and development. At NTU, students are able to tailor their own programs of study to meet their specific needs and fulfill their particular aspirations. They are expected to synthesize the delivered knowledge, to think critically, communicate effectively, and use knowledge and technology intelligently and responsibly to benefit society, and to participate creatively in society. To accomplish all these different and difficult tasks, students at NTU can communicate with their instructors electronically or through mail. Electronic mail, FAX, telephone, mail, express mail, and computer conferencing are the principal means for interaction between students and instructors.

NTU presents great and interesting mission statement, goals, and objectives but fails to explain how they could accomplish them. Based on characteristics of engineers discussed in chapter two, engineers who even have face-to-face interaction with their

instructors have difficulty doing what NTU is asking.

Actually, industries complain about the lack of communication skills among engineers and NTU's media-based delivery system fails to provide this skill to engineers. According to Stackel: "A more serious drawback of NTU--and the one of most cited by member corporations--is that of communication between the instructor (who teaches on a television screen) and the pupil or lack of it" (1988, p.327). Obviously, this problem is rooted in the nature of NTU's delivery system and it will remain unsolved, although as Stackel states: "NTU is attempting to address this issue by increasing contact between instructor and pupil through the use of new communication systems." Nevertheless, the new communication systems--electronic-mail, Internet--have the same problems as satellite communication has.

NTU conducts a continuous evaluation on its programs and services to ensure progress toward achieving institutional (not students' or industries') goals. They may claim that their goals are the same as their students and students' employers, but they need to show these mutual goals. The graduate faculty of each discipline establishes a committee to evaluate the curriculum, course additions, and course revisions. The mechanism of their evaluation is unknown and apparently students and industries have a little impact on evaluation and its process.

The NTU does not provide a cost effective programs for students. Tuition and fees vary from $560 to $905 per credit plus $100 per credit for laboratory courses. To complete all requirements of a certificate program, students need to pay from $6000 to $10,000 depend on the participating university.

Summary of evaluation:

1. NTU does respond to needs of engineers and industries by offering courses in their demanding subjects.
2. Its curriculum is similar to any other university, and therefore is not as practical as engineers need for the retraining purpose.
3. Its course instruction and delivery systems do not respond to engineers' need for communication skills.
4. NTU depends solely on full-time faculty of the participating universities except for its Advanced Technology and Management Program. Engineers prefer to have an instructor who is expert in the field, not one who necessarily is a full-time faculty.
5. Not much information is available about the mechanism of evaluation at NTU and probably students and industries have little impact on it.

Summary. Although training programs are educational processes, they substantially differ from formal schooling. Their differences may lie in goals, duration, setting, participants, and delivery systems. These peculiarities, then, warrant differential treatment and procedures. Unlike the goals of formal schooling which are emphasized in fundamental to advanced subject learning, the goals of training programs are to familiarize the workforce with the latest in knowledge and skills, and consequently, keep participants, as well as their employers, competitive in the marketplace.

There exist many different training models which are developed by either

management, professional trainers, or educators. The problem with these programs lies in their approach, which means they look at the training program mostly from employers' point of view and since many of them possess managerial skills, their model or guideline primarily lacks a meaningful connection with education and its process. On the other hand, educators and experts in the field of education may fail to adequately take into account the employers' needs and expectations. The best solution, apparently then, is to establish a continuous linkage between these two groups, a linkage that enables trainers to successfully integrate the corporate strategies, the future of the marketplace, and the participants' needs and expectation. However, the training developers should never lose sight of the fact that the participants in these programs are different people with different backgrounds, attitudes, and learning styles. Consequently, developing an appropriate delivery system is of utmost importance and a crucial factor for a successful outcome.

Understanding the participants' characteristics and learning styles will lead the providers to design an effective course of instruction. Clearly, however, this represents only one side of a multi-sided issue such as a retraining program. To develop a comprehensive retraining program for engineers, it is essential to thoroughly examine and address all sides. The other sides of the retraining programs are:

1. The employer's business strategies, goals, and future needs.
2. The future needed skills for employees.
3. Selection of effective retraining strategies.
4. Design and development of an appropriate curriculum and delivery system.
5. Development of an effective evaluation and assessment policy.

In response to the needs of engineers and industry, federal and state governments and private agencies have developed a variety of retraining programs. Each of these programs differs from others in objective, mission, goal, cost, and duration. Of all these training programs, the programs of institutes of higher education are more diverse and courses are offered on a more regular basis. Yet their programs are expensive and most unemployed and even employed engineers may have difficulty in afford to participate to such programs. The federal and state training programs are more specific and cost effective but they are mostly seasonal and are available for only local people. On the other hand, the course offerings of professional societies are less expensive and affordable for almost all participants but their offerings are not projectable and consistent.

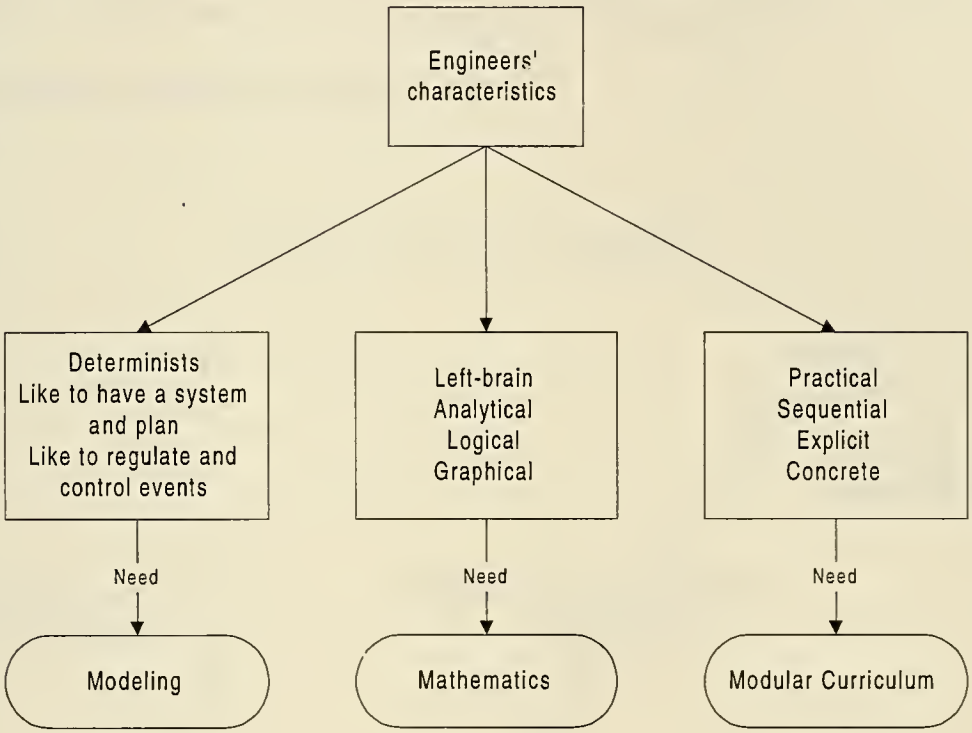
Chapter Six

MATHEMATICS, MODELING, AND MODULAR CURRICULUM IN ENGINEERING RETRAINING PROGRAMS

The participants' needs and the delivery system--as discussed in Chapter Five--are the key factors in all kinds of training programs. These are the interactive factors, which means the delivery system is dependent on participants' needs and participants will develop better knowledge and skills if the delivery system responds to their needs. An effective delivery system, however, is one that has been developed based on an understanding of participants' characteristics and their learning styles.

As discussed in Chapters One and Two, engineers are: left brain types of people, logical, analytical, and graphical. They are practical, sequential, explicit, and concrete types of people who like to have a system and plan. They are determinists and like to regulate and control events. Based on these characteristics, the most effective retraining program for engineers is the one that employs modeling and mathematics. The modular curriculum is the most appropriate approach that responds directly to the sequential and concrete nature of engineers. Figure 1 shows the connectivity of engineers' characteristics and learning styles to modeling, mathematics, and modular curriculum. The necessity of modeling and modular programs for retraining engineers lies in the nature of technology and its advancement. As technology approaches its limit, fundamental changes will not happen as occurred when vacuum tubes were replaced by transistors. It was, indeed, a cultural shock for both engineers and industries when such

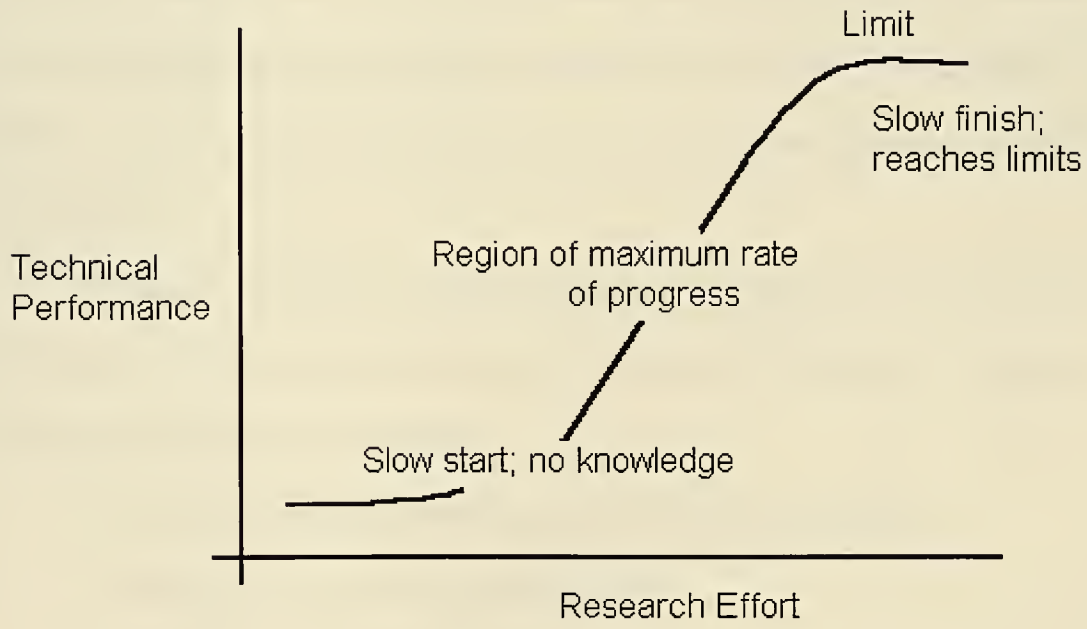
Figure 1. The connectivity of engineer's characteristics to Modeling, Mathematics, and Modular Curriculum



results were achieved. At the present time, however, changes in technology are more horizontal. Changes are mostly transformation from analog to digital world. from hardware to software, from a multiple-chip to single-chip design, and computerization of all aspects of engineering from design to production. In other words, the concepts of engineering have remained virtually the same while their modes and applications are under constant change. For example, the concept of electronic filters has remained exactly the same as when it was introduced the first time, but its mode and application has changed from passive to active and finally to digital type. At this time the technology

begins to be constrained by its limits and the rate of improvement begins to slow down (Jensen, 1986). This phenomena can be depicted as an S-curve in Figure 2. Consequently, engineers who attend a retraining program are at their highest level of knowledge and skills and all they need is limited and explicit knowledge and skills to perform a new task or approach a higher stage of their profession.

Figure 2. The S-curve of technology.



For effective visualization of modeling, mathematics, and modular retraining engineering programs, each of these elements should be defined. It is also required to show the connectivity or dependency of the engineering field to mathematics, modeling, and modular education. The following elements and their role in an engineering retraining program are defined as:

Modeling. Modeling means study of processes and objects in one physical environment by using processes and objects in another physical environment as models that duplicate the behavior of the systems under study. Collins, Brown, and Newman (1989) believe modeling--showing how and why an expert does a task--is one of the methods that are critical to expert teaching.

The complexity of the processes that take place in modern engineering, economic, and other systems is so powerful that those who manage them expect to have useful information about the characteristics of the systems and predictions of the consequences of their behaviors. Although modeling is an effective tool that can be easily applied to any field of study, it is "a natural requirement of almost any engineering course" (Crawley et al, 1994, p.55).

Modeling methods are part of the management process at every stage of human involvement. For instance, to investigate the efficiency and effectiveness of a training program, program providers should:

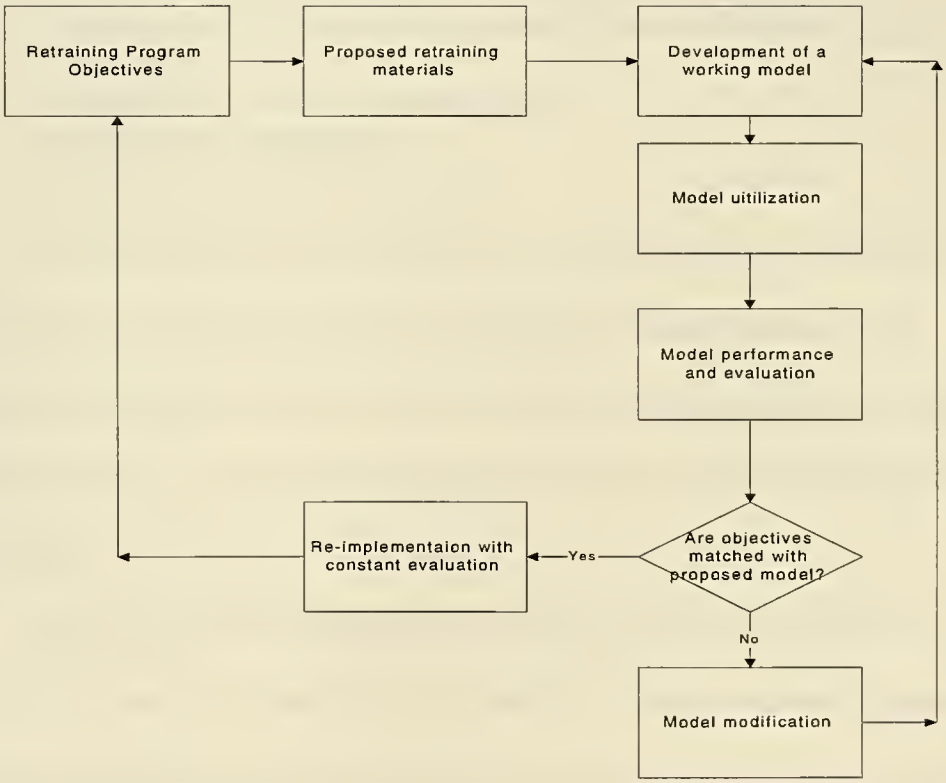
1. Predict the program performance under the proposed condition.
2. Evaluate and assess the proposed program.
3. Identify the points of deficiencies.

To accomplish these tasks, modeling become a powerful tool for them. Figure 3 shows a typical model for an effective training program. This model helps the training program providers to continuously evaluate their proposed program, identify its deficiencies, and improve and modify it in a timely manner.

Modeling has several advantages for engineers; at the design and development

stage, modeling helps engineers evaluate the properties of objects that they do not know yet; when resources and options are limited, modeling may become the only possible method for engineers to design, develop, and optimize new systems; for engineers, modeling is a powerful tool to avoid the consequences of inaccurate technical decisions.

Figure 3. A typical model for an effective training program.



With regard to methodology, engineers proceed in the following ways. For a given problem, they try to gather as much relevant information as possible. Then they search correlations among the involved topics to establish a working model. Subsequently, they

propose solutions, which must be optimized regarding several variables such as time, cost, size, and performance. Rodencker (1984) considers designing process "as a transformation of information, leading from the abstract to the concrete." He proposes eight rules for developing a technical system that starts by defining and abstracting the requirements. Rodencker's rules are:

1. Clarify the task (the required relationship)
2. Establish the function structure (the logical relationship)
3. Choose the physical process (the physical relationship)
4. Determine the embodiment (the constructional relationship)
5. Check the logical, physical and constructional relationships by appropriate calculation.
6. Eliminate disturbing factors and errors.
7. Finalize the overall design.
8. Review the chosen design. (p.10).

What Rodenacker tries to establish is a model that employs mathematics to design a technical system. Rules 4, 5, and 6 are nothing but formulizing the system mathematically. In fact, these three rules are the heart of design process; they show a scientific, efficient, and cost effective design would be possible only by employment of modeling.

Electronic processes and objects are generally used as models because electronic systems have an unusual combination of properties and characteristics. The parameters of the electronic process and the structure of the connection between individual elements can also be changed easily. Along with rapid progress in electronics, the calculation and designing of electrical devices and networks become much more sophisticated task than ever. Consequently, electronic engineers need to continuously improve the methods that are used for mathematical description, numerical analysis and computer-aided design of

electronic devices and systems. Modeling is the only effective approach that responds to the current marketplace which demands fast and inexpensive design and production.

Mathematical modeling has helped electronic engineers extensively to study and investigate the dynamic behavior of electrical networks. Verlan (1985) has developed the mathematical model--integral equation--which is essentially the procedure that finds the integral mathematical relationships between the known source data and unknown network parameters. The following brief description of Verlan's work shows how mathematical modeling helps engineers to study the behavior of a system for further development of a more accurate system.

In solving many digital simulation problems for dynamic system, it is possible to employ the following advantages of the integral approach: the smoothing effect of integral operators; the examination, provision and speeding up of the convergence of iterative methods; and the high stability of direct methods. For example the response of the r-C circuit to the connection of a source of direct current to the interconnected terminals of the resistor and capacitor is described by the non-homogeneous differential equation of

$$C[du(t)/dt] + 1/r\,[u(t)] = 1 \qquad \text{with } u(0) = 0.$$

and also by the integral equation of

$$I(t) + 1/rC[\int I(s)\,ds] = I - u(0) / r \qquad \text{with } u(0) = 0$$

The solution of the equation is attained in the same way as in the case of passive circuit with non-zero initial condition; $I(t) = I \exp[- (1/rC)t]$

Evidently, with: $u(0) = 0$, $I(t) = [I - u(0)/r] \exp[- (1/rC)t]$

Thus the use of integral equations provides a common and convenient means of examining and determining both the inherent and the induced components of processes that take place in linear circuits. The use of integral equations for describing the dynamic behavior of electrical networks will result in a number of specific methods for their quantitative and numerical analysis.

Although modeling reduces design time, increases product quality, and optimizes management, it is one of the most important methods for accelerating scientific and technological progress. Modeling is also intensifying the development of science and the economy, but unfortunately it is absent from American engineering education especially at the undergraduate college level. Several factors play a part in de-emphasizing modeling in the American engineering education. The Grinter report is one that converts engineering schools to research institutes and consequently takes away design from the engineering curriculum. The Grinter (1955) report is one of the most important documents in engineering education in the United States. In 1952, a thirty-member committee of engineering faculty and administrators headed by Grinter reviewed the American engineering education and published a report known as the Grinter report. This report noted that "during the lifetime of present faculties the art of engineering has come to depend greatly upon the basic science of engineering." Although this report emphasized appropriate industrial experience for engineering faculty members, it also indicated that this is not required for those who have special educational background, such as a Ph.D., or have research ability. Consequently, "engineering faculty had become strong in research but were generally unfamiliar with engineering practice, particularly

design" (Ferguson, 1993, p.159).

After World War II, the United States had much better resources and options than any other industrial nation. The defense budget and military spending were high and engineering schools were funded by the armed forces "to keep alive the expectations of a continuing war economy" and logically "only research that contributed to war-making was valued" (Ferguson, 1993, p.159). Almost unlimited resources and options left no room for modeling; instead a philosophy of "trail-and-error" became popular in engineering development and design.

As global marketplaces become more intense, the U.S. industries are adapting themselves to the idea of re-engineering, continuous design, just-in-time strategy, and cost reduction of product. Consequently, modeling is gaining attention among engineers and engineering schools. Most of the engineers in a retraining program have inadequate knowledge of modeling, therefore modeling must be an essential part of any retraining program.

Mathematics. Engineers, in their search for an optimum solution, are far from allowing themselves to be influenced by conventional or pre-set ideas. They must examine comprehensively whether or not the novel and more suitable paths be open to them. To that end, engineers should have knowledge of abstraction, which means ignoring what is particular or incidental, and emphasizing what is general and essential. Mathematics is the only resource for abstraction, therefore engineers must equip themselves to highest level of applied mathematics. In fact, the field of engineering depends extensively on mathematics and engineers must develop a thorough mathematical knowledge if they

want to stay competitive in the workplaces. In this regard, Lynn A. Steen--President of Mathematical Association of America--writes: "Mathematics is both an enabling force and a critical filter for careers in science and engineering....Mathematics is not just one of the sciences, but is the foundation for science and engineering." (Online).

The following brief history of engineering education may provide a comprehensive study on dependency of engineering on mathematics.

In 1735, the first textbook on mathematics for the military corps of engineers was published by Belidor, a French mathematician. The content of this book was mainly basic mathematics and discussed principles of mathematics and its applications in machine and artillery operations or design. In 1747, the first engineering school was founded in Paris and named Ecole des Ponts et Chaussees. Later, after the French Revolution (of 1795) its name changed to Ecole Polytechnique. Gaspard Monge, one of the most famous French mathematicians at the time, introduced a new system of teaching in schools. Timoshenko (1953) describes the new method of teaching as follows:

> "Method of teaching had had an atmosphere of apprenticeship since practical engineers explained to individual students (or small groups) how this or that type of structure must be designed and constructed. If some theoretical information in mathematics or mechanics was required, which was not familiar to the students, the necessary additional instruction would be given by the professor of engineering or by one of the students with better mathematical training." (p.68).

Under the new administration of the school, emphasis on general subjects, including mathematics, became strong. The dominant notion was that every branch of engineering requires some level of understanding in mathematics and natural sciences.

The administrators believed that with a good training of fundamental subjects, students would be able to comprehend any field of engineering. Therefore, engineering students were asked to take mathematics and fundamental sciences in the first two years of their study and engineering courses in the third year. Based on this view of engineering education, some famous mathematicians such as Monge, Lagrange, Poisson, and Fourier joined the Ecole Polytechnique and taught mathematics and mechanics. As a result of the enthusiastic efforts of these great mathematicians, famous scientists and engineers such as Biot, Cauchy, and Navier were among the first graduates of Ecole Polytechnique. The successful outcomes of this first engineering school encouraged other countries to adapt its program and teaching method. For example, the Polytechnical Institutes of Vienna and Zurich were established based on Ecole Polytechnique's program. Russian technical education, in fact, was a duplication of the French system and they invited some lecturers at Ecole to teach in Russian Technical Schools. The United States Military Academy at West Point, the first engineering school in the U.S., was also established as a result of the Ecole's success.

During the eighteenth century, the idea of linking mathematics to engineering and science influenced the works of great scientists and engineers. At the Institute of Applied Mathematics and Mechanics of Gottingen, the tradition of connection between mathematics and its applications (engineering) was established by Guass, a distinguished mathematician, physicist, and engineer . After Guass, the outstanding mathematicians such as Dirichlet, Reimann, and Glebsch continued his idea and work. Felix Kelin, a German mathematician who traveled to the United States to attend the Chicago

International Exposition (the first meeting of engineering educators) and to give lectures at the Mathematical Congress at Evanston, was fascinated by the fact that American universities were mostly supported by private institutions rather than government. Upon his return, he successfully, implemented the American model in Germany and established a direct link between academia and industry. Kelin emphasized the connection between industrial activities and methods of teaching mathematics. He believed that if engineering students took more mathematics, they would be prepared for research work in engineering as well as teaching. Klein's ideas had a great impact on mathematics education in Germany and later, through the International Commission of the International Congress of Mathematics, on the method of teaching mathematics in other countries.

Mathematics in Engineering and Engineering Technology Curriculum. Like any other applied science, engineering operations follow mathematical laws and reasoning. It is much easier to express ideas and relationships in symbols, and manipulate the symbols according to established mathematical procedures, and finally to come up with a set of mathematical expressions which can be converted back to ideas and recommendations. To possess all these skills, a successful engineer needs to have a thorough understanding of a high level of mathematics and be able to utilize the understanding of his or her particular field. Obviously, the necessary degree of comprehending mathematics varies from one discipline of engineering to another. For example, electronic and mechanical engineers need a higher level of knowledge in mathematics than civil or industrial engineers. This expectation of knowledge directly stems from the nature of their fields.

On the other hand, in the field of engineering technology, mechanical and technical knowledge are more important than mathematical knowledge. Engineering technologists who work in these fields are more interested in the "how" of a technological phenomenon than the "why." They are graduates of technical institutes and "the businesses of manufacturing, testing, inspection, quality control, plant operation, and the like more often appeal to" them (National Research Council, 1985, p.12). These domains of technical professions are not influenced by mathematical laws as much as other fields such as development and design. Therefore, engineering technologists need to know just enough mathematics to understand rather than develop some technological phenomena. But one may ask, what degree of mathematical knowledge is "enough" for technologists?

As mentioned above, engineers and engineering technologists have some differences in their tasks, knowledge, and problem-solving approach. Of course there are no universal accepted definitions for engineering and engineering technology but the Accreditation Board of Engineering and Technology's (ABET's Fifty-Five Annual Report, 1983) definitions are more or less accepted by the practitioners of both groups. The following are the definitions currently used by the ABET:

> Engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind.
> Engineering technology is that part of the technological field which requires the application of scientific and engineering knowledge and methods combined with technical skills in support of engineering activities; it lies in the occupational spectrum between the craftsman and the engineer at the end of the spectrum closest to the engineer. Engineering technology is concerned

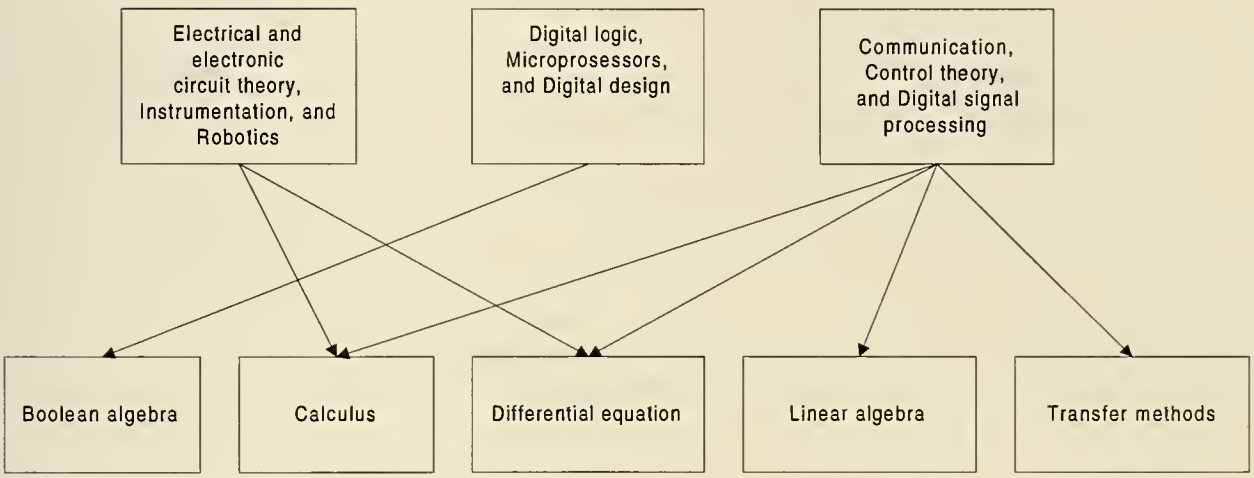
> primarily with the application of established scientific and engineering knowledge and methods. Normally engineering technology is not concerned with the development of new principles and methods.

Comparison of the undergraduate curriculum of both engineering technology institutes and engineering schools in the same field reveals that almost the same number of total semester credit hours are required for completion of a baccalaureate degree. Although the title of technical courses in both of these programs are the same, they differ on prerequisite mathematics and science courses. Technical courses in engineering programs are calculus-based, while in engineering technology they are algebra-based. The curricula of all engineering technology divisions contain fundamental mathematics and science at the college level. Algebra, trigonometry, and basic calculus with an emphasis on problem solving, rather than extensive mathematical proofs, are part of the engineering technology curriculum.

Mathematics requirements for engineering are substantially distinguishable from those for engineering technology programs, since the engineering graduates should understand the "fundamental scientific principles...engineering methods such as analysis and computation, modeling, design and experimental verification, as well as experience in applying these methods to realistic engineering problems and process" (National Research Council, 1986, pp.9-10). Calculus (from introductory to advanced- a two semesters course), differential equations, engineering mathematics (including complex function, linear algebra, and transform methods) are typical mathematics in an undergraduate engineering curriculum. Figures 4 shows the strong connection of the

electronic engineering program to mathematics. The differences between engineers and

Figure 4. The connectivity and dependency of electronic engineering program to mathematics.

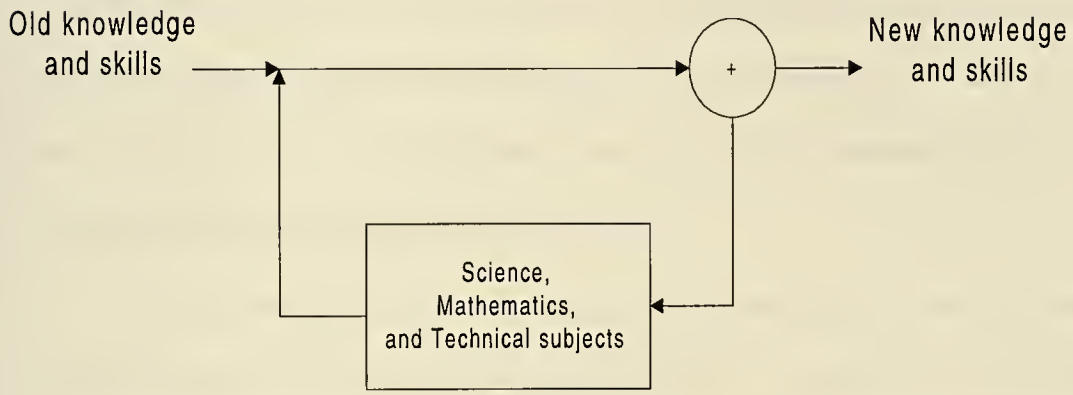


engineering technologists in their paths of training and their role in the industry have a great impact on their retraining criteria. Their retraining programs must be suitable to their needs

and use their previous knowledge and skills to facilitate their learning process. As Thomas (1985) indicates: "In a retraining program, participants should feel that their experience is valid, that it has been properly brought into the course, that it has been taken seriously and used, and that new knowledge and new theory is consonant with that experience and helps to make it intelligible." (p.5). Consequently, It is crucial that the retraining program developers and providers recognize their differences in order to develop a proper retraining program for each group. It is important to employ the scientific approach in both course instruction and course development for engineers and

integrate mathematics and modeling into the program (Figure 5). On the other hand, a retraining program for engineering technologists must be more practical and hands-on and avoid lecturing theory as much as possible.

Figure 5. The process retraining program for engineers and technologists.



Despite the engineers' need for applied mathematics, the traditional methods of teaching mathematics in engineering schools are designed only to equip students with fluent operational knowledge. In the retraining engineering program this deficiency must be resolved and appropriate methods of teaching of mathematics must be employed. To accomplish this task, the retraining program providers must comprehensively study the methods of teaching mathematics at the college level and be able to develop an effective method.

Method of Teaching Mathematics in Engineering Schools. Engineering is nothing but the application of science to daily life. Consequently, engineers need to know how to analyze, synthesize, and correlate data. They also need a well developed sense of

intuition. Current engineering curriculum is almost entirely based upon abstract and logical reasoning and students who cannot reason at the formal level most likely will not be able to complete their engineering studies. Simultaneously, engineering subjects heavily depend on mathematics. For example, calculus applies among other things to the theory of gravitation, heat, light, sound, electricity, magnetism, flow of liquids or charges, and the design of aircraft. The first step in any system design and analysis is modeling and mathematics which is the most powerful modeling tool. Clearly, engineers well versed in mathematics can engage in abstract and logical reasoning, and model building and successful execution of their tasks.

Despite the needs of abstract reasoning in engineering study, teaching methods are mostly based upon ordinary reasoning on logical basis, or application of certain deductive rules. What an engineering student learns is how to apply a mathematical equation or operator to an explicit technical problem. Although, this might be appropriate for some activities, certainly it is not a proper method in engineering education because it takes away creativity from students.

Engineers need to know mathematics to formulate, analyze, and optimize the functionality of the phenomena in order to design and develop a system. Formulating a technological phenomena is not just writing a series of trivial letters, numbers, and signs. Mathematics also helps to write a process in a shorter way which can be read easily, said more quickly, and understood more simply than the case of conventional writings. Mathematics is a universal shorthand language that engineers and scientists may use to communicate with one another in their efforts to solve problems or design a product. But

unfortunately, the current method of teaching mathematics to engineering students turns them into good mathematical illustrators who are only able to solve concrete problems. Sawyer (1950, p.26) calls this method of teaching "bad teaching" and defines it as a "teaching which presents an endless procession of meaningless signs, words, and rules, and fails to arouse the imagination." As was mentioned earlier, the engineering curriculum is almost entirely based upon abstract and logical reasoning. On abstract reasoning and imagination Sawyer writes:

> "It is impossible to imagine any event in perfect detail. In attacking any problem, we simplify the situation to a certain extant. We do not bother about those fact which seem unimportant. The result of our reasoning will be correct if the picture for our imagination is, not exactly correct, but sufficiently correct for the purpose in hand. This process of forgetting unimportant details is known as abstraction. Without abstraction, thought is impossible." (p.31)

In most engineering schools and technical institutes, faculty award students the best grade if they can find exact and correct answers for the given concrete problems. In fact, lack of imagination and inability to engage in abstract thinking is one of the most important factors contributing to inadequacy of recent engineering graduates and their failure to meet the needs and expectations of industry (Watson, 1992).

Creativity is the end result of human imagination and creativity breeds innovation, which is the ultimate ambition of any engineer. Stark Draper (1968) emphasizes the role of engineers as creators and innovators of technology and relates the future and survival of the United States to advancement of its technologies as he argue as following:

> "Today, this superiority of the United States is being challenged by countries with tremendous resource who are strongly motivated and vigorously working to tip the balance of power toward themselves. In these endeavors, technology is universally recognized as basic and one of the essential competitive factors. It follows that creativity, the source of technological advance, is of great importance not only for national progress, but perhaps for survival itself." (p.32).

Imagination and creativity attributes are believed to stem from the right hemisphere of the human brain. According to the theory of left and right-brain specialization, engineers are more left-brain oriented people, although they may possess some characteristics of right-brain persons such as approximation, development, and creativity. Hudspeth (1994) criticize the dominant of left brain learning in educational system and explain why educational systems ended up with this approach of learning. According to them:

> Unfortunately, educational processes have become dominated by left-brain learning. It is quicker, easier, and more measurable than right-brain learning; it fits closer to learning objective. Advanced degrees tend to select students most successful at left-brain operations, and these students subsequently become the educators. A transformation that should be facilitated in the education of any modern engineering students involves a shift from the singular dependence upon the left-brain with its emphasis on the equation for the right answer to also include the nonlinear, right-brain with its ability for holistic analysis and synthesis." (p.4).

There are other problems associated with teaching mathematics. Some educators believe that the problems lie in the content of mathematics courses. Others are concerned with the insufficient use of software, calculators and other computational machines. Still other groups are concerned with the underlying process of reasoning and logic involved in mathematics learning. In 1988, Mathematical Association of America (MAA) conducted

a survey about weaknesses in teaching and methods of improving the teaching of calculus for the new century (Anderson and Loftsgaarden, 1988). The survey contained only two questions:

1. What are the principal weaknesses in calculus instruction?
2. What can be done to improve calculus instruction?

More than half of the responses were concerned with the content of current calculus courses. The following are the most common responses to the first question: too mechanical, rote, lack of relevant problems, lack of reality, lack of emphasis on understanding the concepts, not using computers and calculators, using bad textbook, trying to cover too much material, and teaching by unmotivated teachers with bad techniques.

With regard to second question, one could conclude that there are two trends of thought among educators. First, many of them believe in the "learning by doing" approach. They are more concerned with technical aspects of problems and results. For this group of educators, all problem solving is limited to concrete and "hands-on" objects and problems. They are result-oriented people who are happy with a chain of short-term successes. They place emphasis on the extensive use of electronic computing machines rather than on understanding the process of problem-solving. Clearly, all electronic computational machines are a necessary part of today's education, but extensive use of them will take away creativity from learners.

On the contrary, a second type of engineering educator believes in a "learning by understanding" approach. For them, "thinking is definitely abstract and can be

summarized as 'if . . . , then . . . , therefore, type reasoning" (Stonewater, 1976, p.129). Although the participants in this survey were mathematics educators, their opinions are very close to those of many engineering educators. Of course, their suggestions may improve teaching calculus for mathematics students but not for engineering students. In fact, one problem with engineering education is the teaching of mathematics by mathematicians. Lecturing is their primary delivery system, standing in front of the classroom and relying on words and static symbols or drawing. As stated earlier, engineering students need the ability to think abstractly, but not to work on abstract objects. In such a mathematics class, the difference between abstraction itself and working with abstract objects is not thoroughly clear.

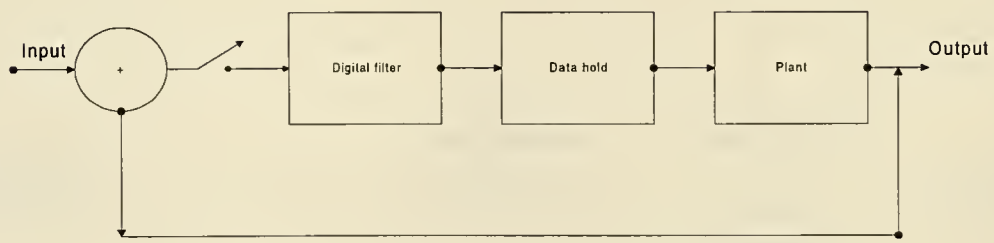
In summary, it is appropriate to claim that mathematics is an essential tool for engineers to analyze, design, and optimize their products. Consequently, retraining engineering program developers must integrate mathematics in all aspects of programs. On the other hand, engineering technologists do not need much mathematics and their retraining program must be more hands-on and practical. Program developers should recognize the differences between engineers and engineering technologists and design a different program for each group.

The teaching of mathematics to engineers should be based on abstract and scientific reasoning. This is the only method that generates innovative engineers which industries need more than ever.

Mathematics and an effective engineering retraining program. At the end of the twentieth century, all aspects of human daily life are in the process of converting from

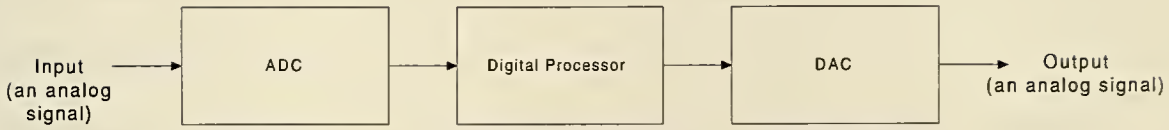
analog to a digital--computerization of the society. In the field of engineering, for accurate, faster, and easier analysis and computation or for precise design and control of a system, engineers simply transfer the natural signals (analog) to a man-made signals (digital). At the present time, digital communication, digital control, and digital signal processing are the most demanded skills in electronic engineering. Many engineers need to be retrained in these areas to stay employed or find a better position. All these demanding areas in electronic engineering have the same ground, which is transformation of their analog signal and frequency domain to digital signal and Z-domain. This transformation is possible only by mathematics. For instance, a digital control system (Figure 6) consists of a digital filter, data hold, and plant.

Figure 6. The block diagram of a digital controller.



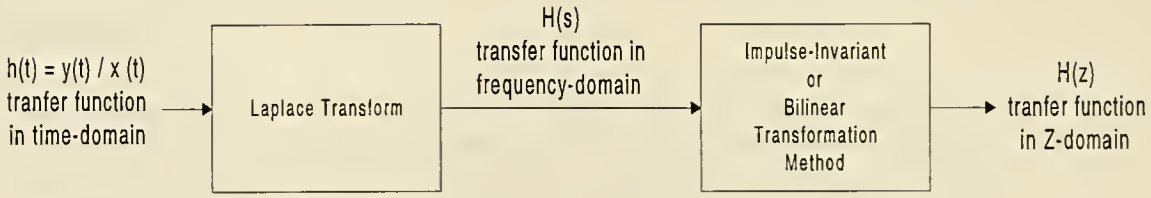
Both digital communication and digital signal processing require digital filters. On the other hand, a digital filter (Figure 7) is nothing but conversion of an analog filter through: an analog-to-digital converter (ADC), a digital processor, and a digital-to-analog converter (DAC).

Figure 7. A typical block diagram of a digital filter.



In digital filter design, engineers first find its transfer function in a time domain, then use Laplace transforms to convert it to a frequency domain and finally use Z-transformation to convert it to Z-domain. These processes are possible only with help of advanced mathematics. Figure 8 illustrates the process of departing from analog to digital transfer function.

Figure 8. The process of converting an analog transfer function to its digital counterpart.



As mentioned in the above statement, a particular set of mathematical equations will help engineers to learn three different demanding areas in electronic engineering. The retraining program providers can easily develop a module which contains all needed mathematics and offer it for three different retraining groups. They also can apply this

module to any other training program that relates to digital filters. Obviously this is a cost-effective approach in training course design. It is also a cost-effective method for participants, since they need to be retrained only for a technical subject if they want to shift their skills.

Modular Program. As discussed earlier, engineers are practical, concrete, explicit, sequential types of people and prefer to have a system and plan. A modular program is one from which engineers will benefit most and which responds directly to their educational needs.

Participants in a retraining program do not possess the same level of knowledge and skills. Consequently, modularization of a program--dividing it to several modules which each depends on the last one--will help participants begin and finish any segment of the program based on their current knowledge and skills. A modular program also gives participants the opportunity to complete their program based on their own rate of learning and understanding. Tracy (1984) believes the traditional training programs are designed to:

> "Teach the total job, with all its tasks, elements, and knowledge supports, to all trainees. This practice ignored differences in employee needs, prior training, past experience, and current or projected job assignment. And for this reason, training and development programs have often been wasteful. By using the modular approach, it is possible to provide training program tailored to individual needs thereby save both time and money. The modular approach enables the training staff, line supervisors, and employees to select specific modules needed by the employee. This is a benefit not only to the organization but also supervisors and employees" (p.306).

The engineering field is the perfect candidate for a modular program since modularity lies in its nature. In engineering an essential part of the problem-solving method involves step by step analysis and synthesis. Engineers always proceed from the qualitative to the quantitative situation through several steps, each new step being more concrete than the last. "After each step, it may become necessary to upgrade or improve the results of the last; that is, to repeat it at a higher information level, and to repeat until the necessary improvement has been made" (Pahl and Beitz, 1984). This is a process known as reengineering, redesign, or continuous improvement and became very popular in recent years in the American industries.

Splitting some elements of the retraining program--course content and instruction--into steps ensures that the essential links between objectives, planning, implementation and checking are maintained. Every step (module) involves, first, a confrontation of the problem with what is already known. The intensity of this confrontation depends on the participants' knowledge, ability, experiences, and skills. Based on these criteria, participants may bypass one or more modules. The following shows the progress in a linear modularity.

------More concrete------>

------(1)------(2)------(3)------>

------Conversion of information------>

Unlike the traditional method of evaluation which takes place at the end of program, the modular program gives providers the opportunity to decide whether to

continue, revise, or terminate the program at any stage. Modular programs prevent the overtraining or undertraining of employees and consequently is the most effective type of retraining or training program.

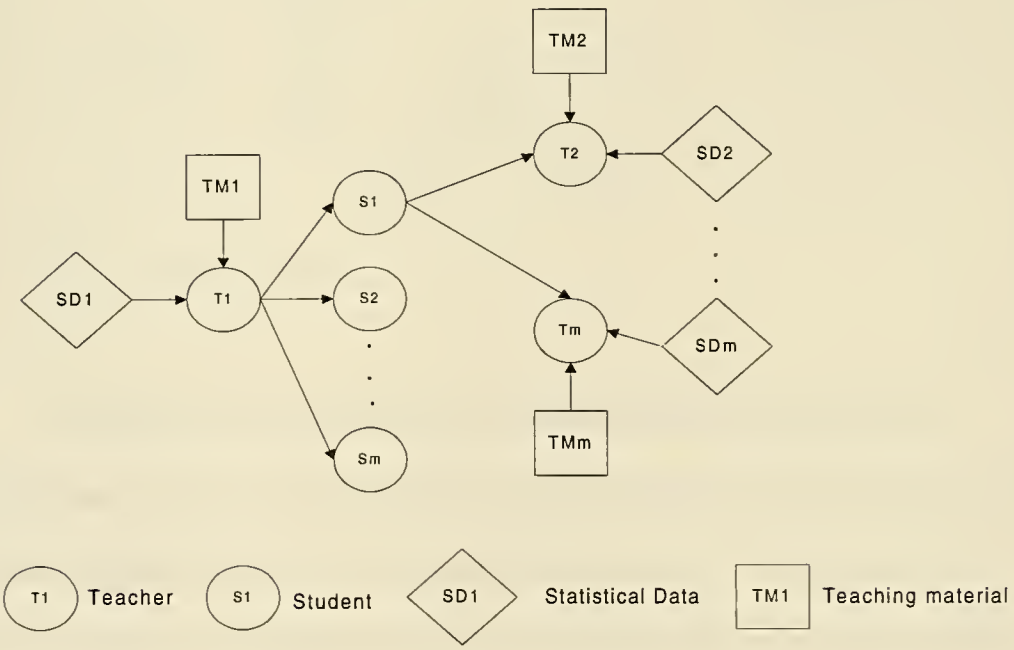
Modular training is the same as Case Method education. Shapiro (1994) compares several approaches to developing knowledge and skills. According to him lectures and reading are appropriate for "acquiring knowledge and becomingly informal about techniques," exercises and problem sets are "the initial tools for exploring the applications and limitations of techniques, but "the development of philosophies, approaches, and skills are best served by the case method." Cases are used to extend the learning experience beyond classroom exercises and laboratory experiments.
As the case method of education has had a successful outcome in management and social science areas, modular education which is the technical version of case study will benefit all involved parties in a training program.

Tracy (1984) divides a modular program in to three basic types: linear, branching, and bypass. Linear modularity is the simplest form and each individual module is completed by the trainee in sequence. Branching modularity permits a group of trainees to complete a program for knowledge and skills required by all trainees and knowledge and skills required by only some trainees without duplication or waste of time. In other words, branch modularity gives opportunity to those individuals who want to gain some parallel knowledge and skills at any stage of training programs. Bypass modularity allows each individual to receive only those knowledge and skills that he or she needs in a training program. The bypass also helps trainees to choose and pace their own program within a

general retraining program for all employees.

The idea of modularization can be also applied to teaching method and course design. The elementary conventional teaching and learning system (Samoilov, 1990) includes students (S), teacher (T), teaching material (TM), and certain statistical data (SD) which characterize the result of the teaching (Figure 9-a). In this system, each student interacts with several teachers with different teaching styles. The Modular teaching system (Figure 9-b) adds a teacher supervisor (TS) who appraises the students'

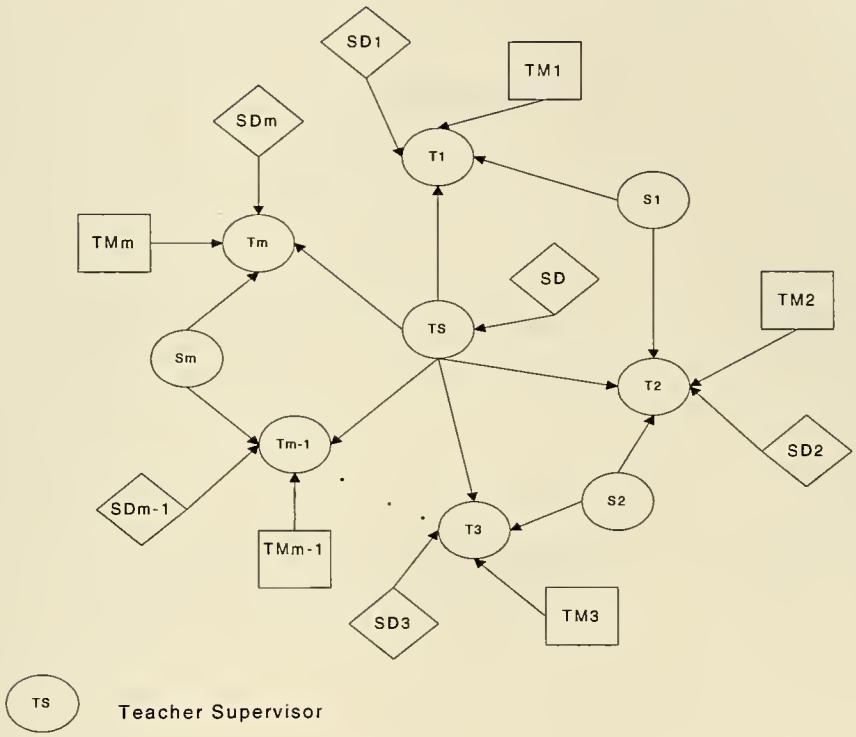
Figure 9-a. The conventional teaching and learning system.



performance and assigns the most useful teacher for a group of students with common knowledge, skills, and learning styles. Students also can select their own teacher based

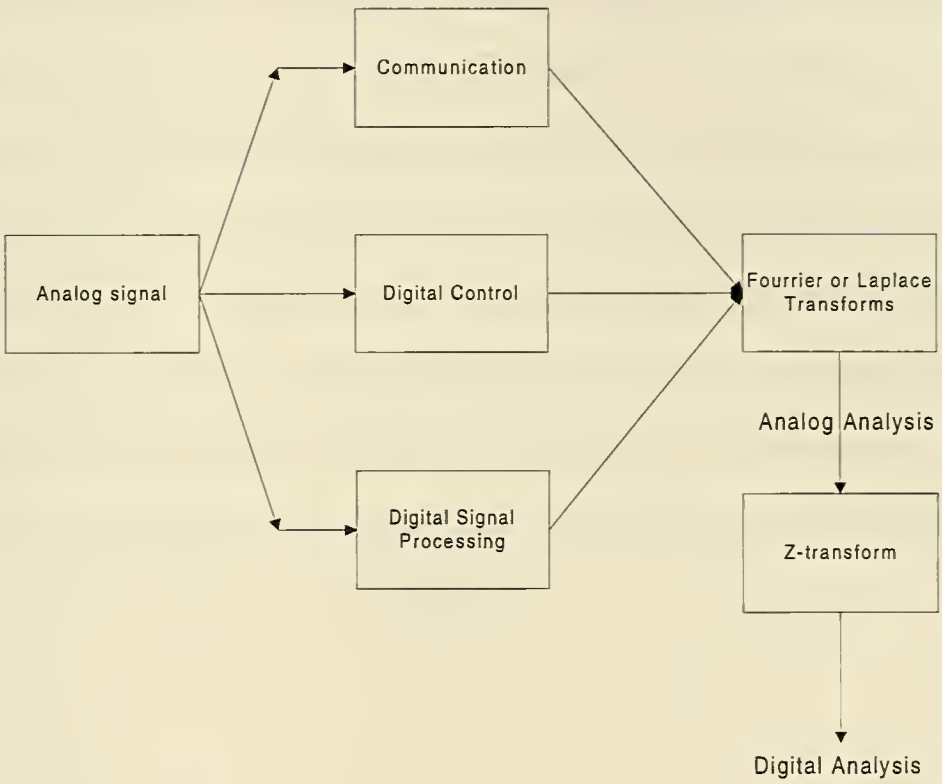
on their needs.

Figure 9-b. The modular teaching and learning system.



Modular course design is based on branching and bypass modularities. Participants can select a path that responds to their needs. Modular course design also helps to duplicate a particular module (s) in different courses. In fact, one of the advantages of modular programs is their reusable and replaceable nature. Modular programs are designed such that the demanding modules can be distilled from several programs and joined to create a new customized training program (Figure 10).

Figure 10. A typical modular course design.



Summary. The successful outcome of any retraining program is highly dependent on how the participants learn and how effectively they can function at the workplace after completion of the retraining program. Consequently, an appropriate delivery system plays a critical role in the retraining programs. The modular program with integration of modeling and mathematics may provide the most suitable retraining program for engineers, because engineers are more practical, sequential, explicit, concrete, left-brain,

logical, graphical, determinists type of people who would like to have a system and plan and to regulate and control events.

Traditionally, American industries and engineering schools have enjoyed relatively unlimited resources. Therefore, American engineers become more "result-oriented" rather then "process-oriented" people. Their attitude toward design and development was based on specific kind of "trail-and -error" philosophy which can be expressed as "let us do it, if it works, fine; if not, try it differently." However, along with industrial competition which is becoming more intense and global, available resources are going to be narrowed down. Consequently, attention of the American industries is shifting from "result-oriented" to "process-oriented" approach. The adoption of mathematical modeling in engineering schools and retraining programs for engineers is the one that may facilitate this transformation.

Conclusion. The engineers' professional career more than that of any other professionals such as teachers, lawyers, or doctors, is highly dependent on economic growth and changes in society and politics. For instance, in the early to mid 1980s, due to substantial increases in the military expenditure, engineers enjoyed high paying jobs and the lowest rates of unemployment. Of course, these are not the only factors affecting the engineering professions. Rapid expansion of global markets and intensified competition results in the survival of innovative companies who are also successful in holding the cost line down. To be innovative, companies need to continuously retrain their employees and furnish them with leading edge technology. On the other hand, lowering the labor cost is possible by reorganization and perhaps trimming the number of employees including engineers. In fact, to eliminate some of the high overhead costs which are associated with full-time employees, hiring contract engineers on a project-by-project basis as well as outsourcing are currently popular trends among the U.S. companies.

To cope with new situations, engineers must continuously upgrade their knowledge and skills. They may have to refocus their knowledge and skills more often, due to frequent technological changes. Engineers also must be equipped with some nontechnical knowledge and skills. Engineers with broad competencies in communication, cross-cultural and interdisciplinary teamwork, and some managerial skills will become a more "independent economic unit," thus having a better opportunity for marketing their knowledge and skills. On the other hand, American industries, especially in high-tech area, have realized that their success in the current and future marketplace highly depends on their investment in training and retraining of their

employees. Under these circumstances, life long learning has become a necessity, not a luxury, in engineering fields.

Both government--federal and state--and private sectors have responded positively to the needs of engineers and industries for retraining. Accordingly, various training and retraining models and guidelines have been developed by professional trainers, managements, and educators. Unfortunately, however, the developers of these models and guidelines, have considered mostly the needs and expectations of employers. Consequently, their models or guidelines are usually not properly rooted in an appropriate educational philosophy and for the most part lack a meaningful connection between training programs and their participants' learning styles and abilities.

What employers expect from a retraining program is that the program educates a group of quality employees who, in turn, can effectively apply their gained knowledge and skills at the workplace. Therefore, even if the main objective of retraining program developers was to only address the needs and expectations of the employers, they must heavily take into account and focus on the characteristics of participants and their respective learning styles. This focus and consideration, however, are precisely what is lacking in most existing training or retraining programs.

A training program is an educational process, albeit with a structure different from that of a more formal schooling. Participants in the training programs are adult. Learning styles as well as goals and objectives of adult learners differs substantially from the goals and learning styles of the younger learners. Adult learners are normally self-directed learners who clearly understand what they want and why they are attending a particular

training or retraining program. They search for training programs with explicit content and goals. They expect their teachers to engage in a process of mutual inquiry with them rather than to transfer their knowledge to them.

However, not even all adults possess the same characteristics and share the same learning style. Characteristics and learning styles of people are rooted in their background and their past learning experience and schooling. Thus, it would be a great mistake to design and develop a universal training model for all adult learners.

Learning is truly a complex and interactive process which is affected by many factors such as society, culture, school environment, past learning experience, teaching methods, and learners' attitudes toward education. To understand how a particular group of people learns, it is important to know who they are. Several studies have been conducted to research study the American engineering students' characteristics, attitudes, and learning styles. Similar studies on engineers, however, are rare. Some obvious differences between engineering students and engineers notwithstanding, the outcome of the research on the first group may fairly be extended to the second group. Therefore, the retraining program developers--in addition to their own research--should utilize all available studies on both groups and design meaningful and effective retraining programs.

Unequivocal generalization of some characteristics to each and every member of any particular group may not be advisable. Nevertheless, it is not very controversial to assert that members of any given group share many common viewpoints and characteristics which in turn form the basis for defining the "norm" within that group. According to the available studies, the American engineers are mostly: logical,

analytical, practical, sequential, explicit, visual, independent, and left-brain type of people. They are determinists and conservative people, who want that systems and plans to control and regulate events. These studies also indicate that the deductive reasoning is the dominated process of reaching conclusions in engineering education.

To design an effective retraining program for engineers, the program developers must consider all of the above factors. There are several measures that program developers should take into consideration. Mathematics, modeling and modular curriculum are the most relevant elements in all types of engineering education including the retraining program. Mathematics is a tool which satisfies the analytical, logical, and explicit characteristics of engineers and their deductive reasoning methodology. An added benefit of mathematics is that it comes with visual tools such as diagrams, pictures, graphs, and flowcharts, i.e., the perfect method of presentation for engineers as "visual" people. Mathematics is the language that enables the engineers to understand, describe, and communicate the science behind their works. For all these reasons, mathematics should be an integral part of an engineering education at all levels.

Scientific inquiry requires that the researchers develop a model for every project that they undertake. These models have some theoretical foundations and are constructed based on a series of assumptions. If the outcome of running a model does not correspond to the expectations of the proposed model or contradicts the theoretical foundations and assumptions, then the model or its foundations or assumptions are revised and modified. Without some type of model, scientific probes and predictions of an event are almost impossible. The field of engineering is a scientific endeavor and is not exempted from

this rule. Engineers are individuals who require a system and plan to function. They work best in a controlled environment where they can control and regulate events governing their experiments. Thus, construction of a conceptual working model before the start of manufacturing is imperative for engineers. Unfortunately, unlike most European countries, e.g., Germany and Russia, the idea of mathematical modeling is absent from most engineering curricula in the United States. The most important reason for this phenomenon may lie in the relative abundance of resources, especially in defense related industries, at the American engineers' disposal. Along with intensification of global competition, tremendous effort to reduce the cost of a product, and shift from mass to lean production in the American industries, modeling is going to become a popular method in engineering professions.

The participants in a retraining program are those who do not seek another degree. Rather, they want to extend or upgrade their knowledge and skill. Therefore, knowing how they learned in the past would be very important to the program developers. For most engineers, the Personalized System of Instruction (PSI) is the past learning experience. In the PSI method, the course material is divided into units and the student's task is to learn and complete each unit within the framework of the instructor's expectations. This method, in fact, lies with the sequential and concrete characteristics of engineers. Consequently, in a retraining program for engineers, the modular curriculum and course design may yield the most desirable outcome.

Digitalization of most aspects of human life has brought many changes not only in the electronic engineering area but to all engineering disciplines. Consequently, the trend

in engineering is going to be more interdisciplinary. For instance, mechatronics--the intersection of mechanical systems, electronics, and control software--is a new and powerful idea in today's product design process or the manufacturing control process. Those retraining program developers who aim for the future should consider the interdisciplinary program very seriously. They should design modular interdisciplinary programs that respond to needs of engineers in different disciplines. They should also develop models and mathematical models to facilitate the process of retraining for all engineers.

Mathematical modeling is a powerful tool in engineering that enables its users to minimize time and cost in design process. In addition, usage of mathematical modeling facilitates the process of redesign or concurrent engineering, a relatively new addition to the American engineering education. In recent decades, the global positions of several American industries have been lost and the overall U.S. balance of trade has deteriorated. Non-U.S. products, especially in industries such as consumer electronics and automobile, not only internationally forced a retreat upon American manufacturers, but also domestically captured a sizeable portion of their market share. The failure of American engineers to come up with an effective design, as compared to the Japanese and European engineers, is often referred to as the root cause of this phenomenon. To remedy the situation, the American engineers must adjust their approach to the art of design and be able to continuously modify and redesign. This, in turn, is best accomplished through adoption of scientific approach to design, i.e., mathematical modeling. Mathematical modeling is the only sensible alternative to the traditional "trial-and-error" approach and

its time consuming and costly process, as well as sub-optimal results. American engineers have all the potential to outperform their Japanese and European counterparts. A revision of the engineering education process, a fresh approach, and a change of attitude toward mathematics and modeling, however, is prerequisite to this success.

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Appendix A. Creation of a Mathematical Model to Design a Digital Filter.

Mathematics is a tool, not a science, that will help engineers to understand, analyze, and solve some particular physical phenomena. Like any other tool, before studying it in detail, users should know when it is used, how it is used, and what it is used for. The following steps show how engineers can employ mathematics as a tool in their work (Moussavi, 1985, p.2).

1. To discover and rediscover a number of related facts and figures about the problem in the hand.
2. To show what follows from what.
3. To arrange facts in a mathematical model.
4. To show the relevancy and connectivity of mathematics and engineering.
5. To employ all existing approaches including usage of mathematical software to solve the considered model.

To consider all above steps in a digital filter design, a design engineer needs to collect all possible information about that particular filter such as: the order of the filter (first, second,...), type of filter (low-pass, high-pass, Butterworth, Chebyshev, ...), and its cut-off or center frequency. The next task is to develop a mathematical model for an analog filter, the existing counterpart to a digital filter, with given specifications. The mathematical model for a filter is nothing but the mathematical relation between its output and input signals, a transfer function. Transfer function, indeed, shows the connectivity of engineering and mathematics. To analyze the behavior of the filter, a design engineer needs to convert the transfer function from time to a frequency domain by using Laplace transform. The transfer function of an analog filter in a frequency

domain is:

$$H(S) = Ai/(S-Pi)$$

To obtain the transfer function of a digital filter, all the design engineer needs to do is to take the following steps:

1. To use impulse response method or any other method to find the transfer function in frequency domain, H(S), to time domain, h(t).

$$h(t) = Ai[\exp(Pi\ t)]\ u(t)$$

2. Uniformly sample h(t) to find h(nT). Where T = sampling interval.

$$h(nT) = Ai\ [\exp(nPi\ t)]\ u(nT)$$

3. Apply Z-transform to obtain discrete transfer function, H(z), which is a mathematical model to design a digital filter.

$$H(z) = Z[h(nT)] = Ai/\{1-[\exp(Pi)](1/z)\}$$

The above procedure shows that the application of engineering products may change by advancement in technology. But the concept of engineering will remain the same and design engineers could easily adapt themselves to new technologies if they equip themselves with the idea of mathematical modeling.

Appendix B. Logical Approach and Mathematics in Logic Design

The logical approach and development of mathematical models, unlike conventional methods, will boost students' concurrent engineering skill. Concurrent engineering is the requirement skill for engineers in the era of industrial transformation from "Mass" to "Lean" production (Moussavi, 1996).

In the logic design, Karnaugh map (K-map) and McCluskey are the two major methods in simplification of an output. These step-by-step or programmed styles, obviously, will facilitate the simplification process. In many cases, however, these are the only useful methods. Yet, because of their nature--following orders and steps--they will take away imagination, creativity, innovation, and redesign skills from engineers. In recent years, U.S. firms have gone through many changes, both managerial and technological. One of the major changes, is the shift from "mass" to "lean" production. Reduced cycle time, continuous improvement, faster innovation, and concurrent engineering are some of the characteristics of the new mode. To stay competitive in today's job market, engineers should learn those skills which are in demand such as concurrent engineering. The logical approach, along with development of a mathematical model in the logic design, is one that may introduce such a skill to engineers.

Comparison. The following show the process of a full adder (a combinational logic circuit) by using the Karnaugh map, McClusky method, and logical approach. Suppose (A, B, Ci) and (S, Co) represent the input and output of a full adder respectively.

1. Karnaugh Map Method. The truth table, K-map representation, and output Boolean expression of a full adder are:

Truth table for a full-adder

A	B	Ci	S	Co
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	1	1	0	1
1	1	0	0	1
1	1	1	1	1

The K-map of output S

S	Ci'	Ci
A' B'	0	(1)
A' B	(1)	0
A B	0	(1)
A B'	(1)	0

The K-map of output Co

Co	Ci'	Ci
A' B'	0	0
A' B	0	1
A B	1	1
A B'	0	1

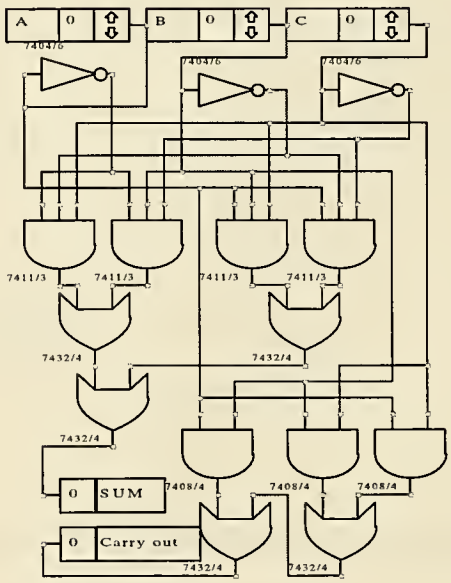
In this design the K-map method is unable to simplify the output of Summation (S), since there are no groups of "1" that can be combined together. Therefore, the (S) output is:

$$S = A'B'Ci + A'BCi' + ABCi' + AB'Ci'$$

There are three groups of two "1" in the K-map represention of the output of Carry-out (Co). Therefore, the Co output is:

$$Co=AB + BCi + Aci'$$

Figure 1. The logic circuit of a full adder using K-map method.



2. McCluskey Method. The (S) output and (Co) output representation of a full adder in the McCluskey method are: $S = \Sigma m (1,2,4,7)$ and $Co = \Sigma m (3,5,6,7)$ respectively. The simplification of outputs (S) and (Co) according to the McClusky method are:

$S = \Sigma m (1,2,4,7)$

List 1

1
2
4

7

Based on McClusky's method, it is impossible to simplify the summation output. Therefore, all minterms are prime implicants and the Boolean expression of the output is exactly same as the one found by the K-map method, which is S = A'B'Ci' + A'BCi' + AB'Ci' + ABCi

$Co = \Sigma m (3,5,6,7)$

List 1	List 2
3	7,3 (4) *
5	7,5 (2) *
6	7,6 (1) *
7	

There are three prime implicants for the (Co) output, therefore, the final Boolean expression is: Co = 7,3 (4) + 7,5 (2) + 7,6 (1) = BCi + ACi + A B, which is exactly the same as K-map's result.

3. Logical Approach. To design an electronic circuit either logically or mathematically, one should clearly understand the characteristics of input(s), output(s), and their relations.

In the combinational logic circuit, the truth table is one that provides such information. For instance, to design a full adder, the designer should take the following steps:

1. Look at the truth table and investigate the possible relation between those inputs which turn output "ON".

2. Use his or her imagination and knowledge in order to find a pattern between inputs and output.

3. Write a mathematical expression that describes comprehensively the functionality of the output.

4. Analyze the output to find out whether or not it satisfies all requirements.

In the logic design, there are many cases a mathematical model will describe more explicitly than a truth table. The Mathematical model will help designers to continuously redesign and modify their works in the least possible time and consequently bring the cost of a prouct down. The following show that a logical approach leads the designer to design a full-adder with less components, and therefore, to come up with a smaller circuit in a cost effective manner. The description of the truth table of a full-adder can be summarized as follow:

1. The (S) output is ON if and only if:

   a. Input A = OFF, and either input B or Ci = ON which means S = ON when the relation between inputs is equal to A' (B' Ci + B Ci').

   b. Input A = ON, and either input B or Ci = OFF which means S = ON when the relation between inputs is equal to A (B' Ci' + B Ci).

Consequently, the Boolean expression of (S) output is the combination of part (a)

and part (b) which in the digital logic definition means:

$$S = \text{part (a)} + \text{part (b)} = A \oplus (B \oplus Ci).$$

2. The (Co) output is ON if:

a. Input A = ON and either input B or Ci = ON, which means Co = ON when the relation between inputs is equal to A ($B \oplus Ci$).

b. Inputs B and Ci are both ON, which means Co = ON when the relation between inputs is equal to BCi.

Consequently, the Boolean expression of output Co, is the combination of part (a) and part (b) which in the digital logic definition means:

$$Co = \text{part (a)} + \text{part (b)} = A (B \oplus Ci) + BCi$$

Cost Analysis. Cost analysis is a major issue in engineering design. In digital logic design, minimum gates mean the minimum chip and consequently, the smaller printed circuit board and the lower production cost. To maintain the cost prodiction as low as possible, a digital designer should keep down the number of gates and their varieties in order to reduced time cycle, labor cost, inventory, and warehouse expenses.

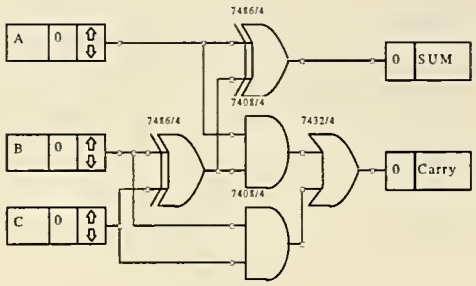
For instance, to design a full-adder based on the K-map or McCluskey methods, a designer needs: 3-inverter + four, 3-input AND gate + three, 2-input AND gate + one, 4-input OR gate + one, 3-input OR gate, a total of twelve gates. In this case, the designer has the opportunity to minimize the variety of gates. Yet he or she still needs six different chips:

1-7404 (inventers) + 3-7408 (2-input AND gate) + 2- 7432 (2-input OR gate).

If the Same designer chooses to use the logical method (Figure 2), he or she needs

only: three 2-input Exclusive-OR (7486) + two 2-input AND (7408) + one 2-input OR (7432). In other words, the designer needs only five gates or three chips to design a full-adder.

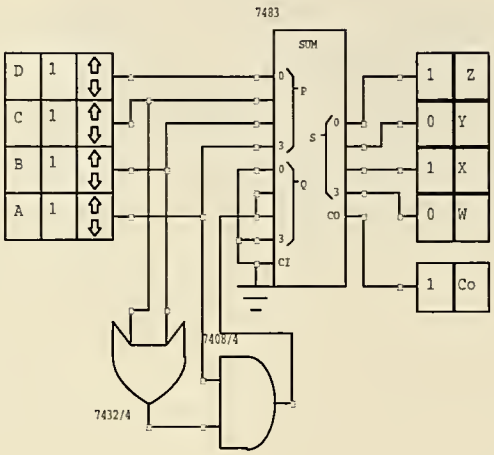
Figure 2. The logic circuit of a full-adder using logical approach.



In many cases, the "logical and mathematical model" approach may help the digital design engineers to come up with a simpler design. The simplest example in this regard is the design of a Binary-Coded-Decimal (BCD). In addition to employing several extra logic gates, the traditional methods of using either K-map or McCluskey may convert some non-decimal numbers to a BCD number which are incorrect. On the contrary, the mathematical approach converts only decimal numbers to their BCD equivalent with less design time and fewer logic gates. To convert decimal numbers to their BCD equivalent, one can easily add "0" if the decimal number at input is less than "10" and add "6" if it is equal to or greater than "10". This mathematical process shall be done by a logic circuit. The binary equivalent of decimal numbers which are equal to or greater than "10" have "1" at their most significant bit and are followed by either "01", "10", or "11". The Boolean expression of such a condition is equal to A(B+C).

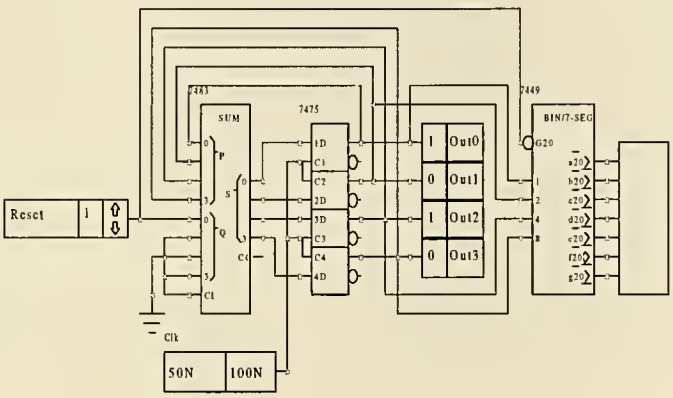
Therefore, by using a 4-bit full-adder, one AND gate, and one OR gate, the logic designer can easily design a 4-bit binary to BCD converter as shown in Figure 3.

Figure 3. The logic circuit of a BCD detector using the logical approach.



A simple mathematical model can help design engineers to design a less expensive binary or decimal counter with minimum possible design time. A counter is a device that shows series of numbers and repeats them after a given cycle. For instance, a decimal counter shows the numbers of “0" to “9" and will repeat them continuously. The counting procedure can be done by a simple addition of the old number to decimal number of “1". Therefore, a design engineer needs only a 4-bit full-adder and a simple memory device such as a D-flip-flop to design such a counter. In addition to needs of more components, the traditional approach in logic design, which is based on simplification of the state table, requires more design time than the mathematical approach. This example, once again, shows that mathematical modeling will help design engineers to come up with a cost effective and better design.

Figure 4. The logic circuit of a binary and decimal counter using mathematical modeling.



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